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ABSTRACT

The manual is designed as a self-study text for use by personnel of the Navy and Naval Reserve who are preparing to meet professional requirements for advancement in the rating of Aviation Electronics Technician. The document opens with a review of leadership and qualifications for the Aviation Electronics Technician rating. Other chapters cover publications, drawings, and schematics; elementary physics; special tools and materials; avionics support equipment and maintenance; airborne computers; electrical power and ground cooling systems; airborne communications equipment; airborne navigation equipment and radar; electronic countermeasures; and security. There are four short appendixes: Formulas, Symbols, Laws of Exponents, and the Greek Alphabet. An index concludes the volume. (NH)

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AVIATION
ELECTRONICS TECHNICIAN 3 & 2

NAVAL TRAINING COMMAND

RATE TRAINING MANUAL NAVTRA 10317-E

DEPARTMENT OF HEALTH
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

ED 099480

PREFACE

This Rate Training Manual is prepared especially for Navy and Naval Reserve personnel who are preparing for advancement to AT3 and AT2. Selection of its content is based upon the "quals" for AT2 and AT3 listed in the Manual of Qualifications for Advancement, NavPers 18068 (Series). However, this manual does not cover all of the qualifications, the remainder being covered in basic Rate Training Manuals which are listed in the AT section of the Bibliography for Advancement Study, NavTra 10052 (Series).

Personnel preparing for AT3 are not responsible for the entire content of all manuals referenced in NavTra 10052, but only for those areas which cover "quals" for the AT3. Personnel preparing for AT2 are responsible for the entire content of this manual (AT 3 & 2) and also for the material listed in NavTra 10052 for both the AT3 and AT2. Separate nonresident career courses are available for AT3 and AT2 and reflect the division of study materials. Those taking the nonresident courses are directed to study the appropriate material in all referenced manuals.

This Rate Training Manual was prepared by the Navy Training Publications Center, NAS Memphis, Millington, Tennessee, for the Naval Training Command. Credit for technical assistance is given to the Naval Air Technical Training Center, NAS Memphis; the Naval Examining Center; and the Naval Air Systems Command.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

Chapter Page

1. Aviation Electronics Technician rating 1
2. Publications, drawings, and schematics 10
3. Elementary physics 40
4. Special tools and materials 93
5. Avionics support equipment 124
6. Avionics maintenance 191
7. Airborne computers 230
8. Electrical power and ground cooling systems 257
9. Airborne communications equipment 279
10. Airborne navigation equipment 313
11. Airborne radar 354
12. Electronic countermeasures 373
13. Security 398

Appendix

I. Formulas 405
II. Symbols 409
III. Laws of exponents 417
IV. Greek alphabet 418

Index 419

CHAPTER 1

AVIATION ELECTRONICS TECHNICIAN RATING

This training manual is designed as a self study text for use by those personnel of the Navy and Naval Reserve who are preparing to meet the professional (technical) qualifications for advancement to Petty Officer Third Class and Petty Officer Second Class in the rating of Aviation Electronics Technician. Minimum professional qualifications for advancement in all ratings are listed in the Manual of Qualifications for Advancement, NavPers 18068 (Series). The qualifications list which was used as a guide in the preparation of this manual was current as of the August 1972 revision. Therefore, changes in the qualifications occurring after the 1972 revision may not be reflected in the information presented here.

This manual does not contain coverage on all "quals" listed in the "Quals" Manual. Some of the "quals" listed are wholly or partially covered by the following basic Rate Training Manuals:

Tools And Their Uses, NavPers 10085-B, Chapters 1, 4, 7.

Basic Electricity, NavPers 10086-B, all chapters.

Basic Electronics, Vol. 1, NavPers 10087-C, Chapters 2-8, 10-27, 29.

Basic Electronics, Vol. 2, NavPers 10087-C, Chapters 2, 4, 13.

Synchro, Servo, and Gyro Fundamentals, NavPers 10105, Chapters 1-4.

Basic Machines, NavPers 10624-A, Chapters 1-9, 15.

It is important that personnel studying for advancement be familiar with the content of these chapters; advancement examinations will also be based on this material as well as the material covered in this Rate Training Manual.

This chapter provides information on the enlisted rating structure, the AT rating, requirements and procedures for advancement, and references that will help you in working toward advancement and in performing your duties as an AT. Also included is information on how to make the best use of Rate Training Manuals. It is therefore strongly recommended that you study this chapter carefully before beginning intensive study of the remainder of the manual.

ENLISTED RATING STRUCTURE

The present enlisted rating structure consists of general ratings and service ratings.

General ratings identify broad occupational fields of related duties and functions and may be held by both Regular Navy and Naval Reserve personnel. This type rating provides the primary means of identifying billet requirements and personnel qualifications, is established or disestablished by the Secretary of the Navy, and is provided a distinctive rating badge.

Service ratings identify subdivisions or specialties within a general rating which require related patterns of aptitudes and qualifications and which provide paths of advancement for career development. (Not all general ratings have serv-ratings–only some of them.) Service ratings may also be held by both Regular Navy and Naval Reserve personnel and can exist at any petty officer level; however, they are most common at the PO3 and PO2 levels.

NOTE: The term "rate" identifies personnel occupationally by pay grade; "rating" refers to the occupational field.

AVIATION ELECTRONICS TECHNICIAN RATING

The Aviation Electronics Technician rating is a general rating up to E-9. At pay grade E-9 the AT rating loses its identity; all of the avionics ratings are compressed into one rating at the E-9 level. The ATCS, AECS, AQCS, or AXCS who is selected for advancement becomes a Master Chief Avionics Technician, AVCM. Figure 1-1 illustrates the paths of advancement from Airman Recruit to Master Chief Avionics Technician (AVCM), Chief Warrant Officer (W-4), or to Limited Duty Officer (LDO). Shaded areas in figure 1-1 indicate career stages where qualified enlisted men may advance to Warrant Officer (W-1), and selected Commissioned Warrant Officers (W-2 or W-3) may advance to Limited Duty Officer. Personnel in enlisted rates and warrant ranks not in a shaded area may advance only as indicated by the arrows.

Aviation Electronics Technicians inspect and perform organizational and intermediate maintenance on aviation detection, reconnaissance, identification, communication, navigation, display, and special purpose electronic equipment, including target drone and pilotless aircraft equipment. They also operate airborne CIC and electronic warfare (ECM) equipment.

As an Aviation Electronics Technician Third Class or Second Class, your assignment possibilities cover a wide range of duties and responsibilities. Your specific duties will depend to a large extent upon the type of organization to which you are assigned. It is probable that you will be assigned to billets which are concerned with the maintenance of electronic and associated equipment within the responsibility of your service rating. You may be assigned to any of the several types of aircraft maintenance activities.

In an aircraft squadron, your duties are concerned primarily with the avionics division of the maintenance department. You will work under the supervision of the avionics division chief on all routine maintenance functions and on minor repair of electronic and associated equipments. You will also perform such other duties as may be assigned to you by the avionics officer or his representative. In some squadrons you may be assigned in the capacity of plane captain.

In the aircraft intermediate maintenance department (AIMD) of a naval air station, you may be assigned duties similar to those in a squadron. You may also be assigned to a check crew or to a trouble-shooting crew.

On aircraft carriers you may be assigned to a crew which aids in the incorporation of required changes and modifications in squadron aircraft or electronic equipment. You may be required to perform work involving shop tools and services. You may perform more extensive maintenance than that normally performed by the squadron.

One of the billets available to the AT2 is that of instructor in a training activity. Instructor duty may be performed either as a shore duty or as a sea duty assignment.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the Enlisted Transfer Manual, NavPers 15909 (Series).

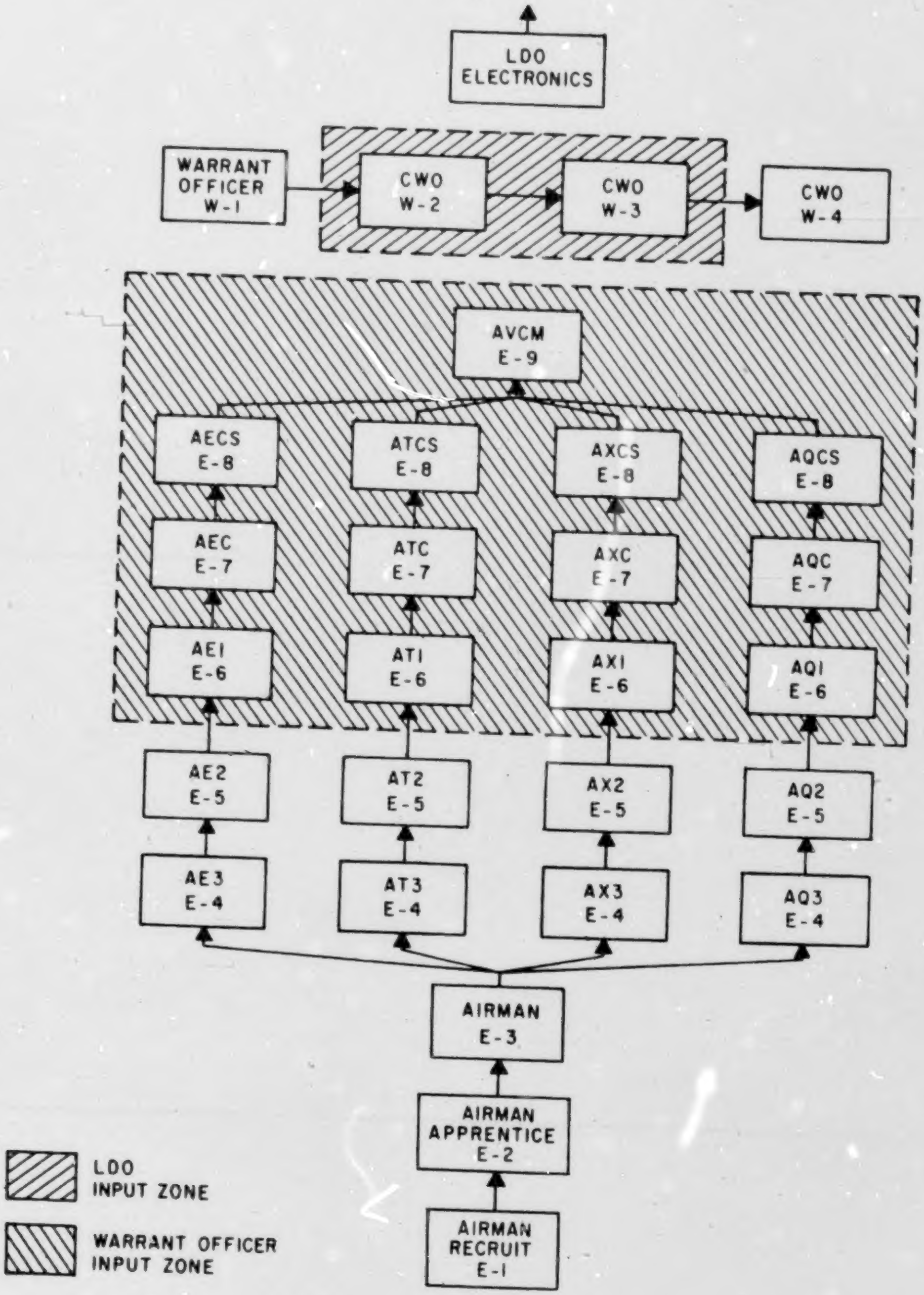
LEADERSHIP

One does not have to be a member of the Armed Forces very long before realizing that more leadership is required of the higher rates. Advancement not only entails the acquisition of superior knowledge, but also the demonstrated ability to handle people. This ability increases in importance as one advances through the petty officer rates.

In General Order No. 21, the Secretary of the Navy outlined some of the most important aspects of naval leadership. By naval leadership is meant the art of accomplishing the Navy's mission through people. It is the sum of those qualities of intellect, of human understanding, and of moral character that enable a person to inspire and to manage a group of people successfully. Effective leadership therefore is based on personal example, good management practices, and moral responsibility. The term leadership includes all three of these elements.

The current Navy Leadership Program is designed to keep the spirit of General Order No. 21 ever before Navy personnel. If the threefold objective is carried out effectively in every command, the program will develop better leaders. As one advances up the leadership ladder, more and more of his worth to the Navy will be judged on the basis of the amount of efficient work obtained from subordinates rather than how much of the actual work he performs.

For further information on the practical application of leadership and supervision, the


LDO ELECTRONICS
WARRANT OFFICER W-1
CWO W-2
CWO W-3
CWO W-4
AVCM E-9
AECS E-8
ATCS E-8
AXCS E-8
AQCS E-8
AEC E-7
ATC E-7
AXC E-7
AQC E-7
AEI E-6
ATI E-6
AXI E-6
AQI E-6
AE2 E-5
AT2 E-5
AX2 E-5
AQ2 E-5
AE3 E-4
AT3 E-4
AX3 E-4
AQ3 E-4
AIRMAN E-3
AIRMAN APPRENTICE E-2
AIRMAN RECRUIT E-1
LDO INPUT ZONE
WARRANT OFFICER INPUT ZONE

AT.1

Figure 1-1.—Paths of advancement.

latest edition of Military Requirements for Petty Officer 3 & 2, NavPers 10056 (Series), should be studied.

ADVANCEMENT

Some of the rewards of advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

The advantages of advancement are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By advancement, you increase your value to the Navy in two ways: First, you become more valuable as a technical specialist in your own rating; and second, you become more valuable as a person who can train others, and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.
2. Complete the required Rate Training Manuals by either demonstrating a knowledge of the material in the manual by passing a locally prepared and administered test, or by passing the Nonresident Career Course based on the Rate Training Manual.
3. Demonstrate your ability to perform all the practical requirements for advancement by completing the Record of Practical Factors, NavTra 1414/1.
4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.
5. Successfully complete the applicable military/leadership examination which is required prior to participating in the advancement (professional) examination.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

Advancement is not automatic. After you have met all the requirements, you are eligible for advancement. You will actually be advanced only if you meet all the requirements (including making a high enough score on the written examination) and if quotas permit.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement? You must study the qualifications for advancement, work on the practical factors, study the required Rate Training Manuals, and study other material that is required. You will need to be familiar with the following:

1. Manual of Qualifications, for Advancement, NavPers 18068 (Series).
2. Record of Practical Factors, NavTra 1414/1.
3. Bibliography for Advancement Study, NavTra 10052 (Series).
4. Applicable Rate Training Manuals and their companion Nonresident Career Courses.
5. Examinations for advancement.

Collectively, these documents make up an integrated training package tied together by the qualifications. The following paragraphs describe these materials and give some information on how each one is related to the others.

"Quals" Manual

The Manual of Qualifications for Advancement, NavPers 18068 (Series), gives the minimum requirements for advancement. This manual is usually called the "Quals" Manual, and the qualifications themselves are often called "quals." The qualifications are of two general types: military requirements, and professional (or technical) qualifications.

Military requirements apply to all ratings rather than to any one particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all other ratings.

Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups; then, within each subject matter group, they are divided into practical factors and knowledge factors. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rate.

The qualifications for advancement and a bibliography of study materials are available in your educational services office. Study these qualifications and the military requirements carefully. The written examination for advancement will contain questions relating to the knowledge factors and the knowledge aspects of the practical factors of both the military requirements and the professional qualifications. If you are working for advancement to second class, remember that you may be examined on third class qualifications as well as on second class qualifications.

It is essential that the "quals" reflect current requirements of fleet and shore operations, and that the new fleetwide technical, operational, and procedural developments be included. For these reasons, the qualifications are continually under evaluation. Although there is an established schedule for revisions to the "quals" for each rating, urgent changes to the "quals" may be made at any time. These revisions are issued in the form of changes to the "Quals" Manual. Therefore, never trust any set of "quals" until you have checked the change number against an up-to-date copy of the "Quals" Manual. Be sure you have the latest revision.

Personnel Qualification Standards

Personnel Qualification Standards (PQS) (OpNav Instruction 3500.34) are presently being utilized to provide guidelines in preparing for advancement and qualification to operate specific equipment and systems. They are designed to support the advancement requirements as stated in the "Quals" Manual.

The "Quals" and Record of Practical Factors are stated in broad terms. Each PQS is much more specific in its questions that lead to qualification. It provides an analysis of specific equipment and duties, assignments, or responsibilities which an individual or group of individuals (within the same rating) may be called upon to carry out. In other words, each PQS provides an analysis of the complete knowledge and skills required of that rating tied to a specific weapon system (aircraft and/or individual systems or components).

Each qualification standard has four main subdivisions in addition to an introduction and a glossary of PQS terms. They are as follows:

100 Series—Theory
200 Series—Systems
300 Series—Watchstations (duties, assignments, or responsibilities)
400 Series—Qualification cards

The introduction explains the complete use of the qualification standard in terms of what it will mean to the user as well as how to use it.

The Theory (100 Series) section specifies the theory background required as a prerequisite to the commencement of study in the specific equipment or system for which the PQS was written. These fundamentals are normally taught in the formal schools (Preparatory, Fundamentals, and Class A) phase of an individual's training. However, if the individual has not been to school, the requirements are outlined and referenced to provide guidelines for a self-study program.

The Systems (200 Series) section breaks down the equipment or systems being studied into functional sections. PQS items are essentially questions asked in clear, concise statement (question) form and arranged in a standard format. The answers to the questions must be extracted from the various maintenance manuals covering the equipment or systems for which the PQS was written. This section asks the user to explain the function of the system, to draw a simplified version of the system from memory, and to use this drawn schematic or the schematic provided in the maintenance manual while studying the system or equipment. Emphasis is given to such areas as maintenance management procedures, components, component parts, principles of operation, system interrelations, numerical values considered necessary to operation and maintenance, and safety precautions.

The Watchstation (300 Series) section includes questions regarding the procedures the individual must know to operate and maintain the equipment or system. A study of the items in the 200 series section provides the individual with the required information concerning what the system or equipment does, how it does it, and other pertinent aspects of operation. In the 300 series section, the questions advance the qualification process by requiring answers or demonstrations of ability to put this knowledge to use or to cope with maintenance of the system or equipment. Areas covered include normal operation; abnormal or emergency operation; emergency procedures which could limit damage and/or casualties associated with a particular operation; operations that occur too infrequently to be considered mandatory performance items; and maintenance procedures/instructions such as checks, tests, repair, replacement, etc.

The 400 series section consists of the qualification cards. These cards are the accounting documents utilized to record the individual's satisfactory completion of items necessary for becoming qualified in duties assigned. Where the individual starts in completing a standard will depend on his assignment within an activity. The complete PQS is given to the individual being qualified so that he can utilize it at every opportunity to become fully qualified in all areas of his rating and the equipment or system for which the PQS was written. Upon transfer to a different activity, each individual must requalify. The answers to the questions asked in the qualification standards may be given orally or in writing to the supervisor, the branch or division officer, and maintenance officer as required to certify proper qualification. The completion of part or all of the PQS provides a basis for the supervising petty officer and officer to certify completion of Practical Factors for Advancement.

Record of Practical Factors

Before you can take the Navy-wide examination for advancement, there must be an entry in your service record to show that you have qualified in the practical factors of both the military requirements and the professional qualifications. A special form known as the Record of Practical Factors, NavTra 1414/1 (plus the abbreviation of the appropriate rating), is used to keep a record of your practical factor qualifications. The form lists all practical factors, both military and professional. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically to the Manual of Qualifications for Advancement and revised forms of NavTra 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rate but which are not identified as minimum qualifications for advancement.

If you are transferred before you qualify in all practical factors, NavTra 1414/1 should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is actually inserted in your service record before you are transferred. If the form is not in your service record, you may be required to start again and requalify in the practical factors which have already been checked off.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-2 through E-8 for his personal record and guidance.

The importance of NavTra 1414/1 should be emphasized continuously. It serves as a record to indicate to the petty officers and officers supervising your work that you have demonstrated proficiency in the performance of the indicated practical factors and is part of the criteria utilized by your commanding officer when he considers recommending you for advancement. In addition, the proficient demonstration of the applicable practical factors listed on this form can aid you in preparing for the examination for advancement. Remember that the knowledge aspects of the practical factors are covered in the examinations for advancement. Certain knowledge is required to demonstrate these practical factors and additional knowledge can be acquired during the demonstration. Knowledge factors pertain to that knowledge which is required to perform a certain job. In other words, the knowledge factors required for a certain rating depend upon the jobs (practical factors) that must be performed by personnel of that rating. Therefore, the knowledge required to proficiently demonstrate these practical factors will definitely aid you in preparing for the examination for advancement.

NavTra 10052

Bibliography for Advancement Study, NavTra 10052 (Series), is a very important publication for anyone preparing for advancement. This bibliography contains a section listing the military references and another section listing the professional references. These sections list required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NavTra 10052 is revised and issued once each year by the Chief of Naval Training Support. Each revised edition is identified by a letter following the NavTra number. When using this publication, be sure that you have the most recent edition.

If extensive changes in qualifications occur between the annual revisions of NavTra 10052, a supplementary list of study material may be issued in the form of a NavTra Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications. If changes have been made, see if a Notice has been issued to supplement NavTra 10052.

The required and recommended references are listed by rate level in NavTra 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class, but remember that you are also responsible for the references listed at the third class level.

In using NavTra 10052, you will notice that some Rate Training Manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY—that is, it must be completed at the indicated rate level before you are eligible to take the Navy-wide examination for advancement. Each mandatory manual may be completed by passing the appropriate nonresident career course that is based on the mandatory training manual; passing locally prepared tests based on the information given in the training manual; or in some cases, successfully completing an appropriate Class A School.

Do not overlook the section of NavTra 10052 which lists the required and recommended references relating to the military standards/requirements for advancement. For example, all personnel must complete the Rate Training Manual, Requirements for Petty Officer 3 & 2, NavPers 10056 (Series), for the appropriate rate level before they can be eligible to advance.

The references in NavTra 10052 which are recommended, but not mandatory, should also be studied carefully. All references listed in NavTra 10052 may be used as source material for the written examinations at the appropriate rate levels.

Rate Training Manuals

There are two general types of Rate Training Manuals. Rating manuals (such as this one) are prepared for most enlisted rates, giving information that is directly related to the professional qualifications. Basic manuals give information that applies to more than one rate and rating. Basic Electricity, NavPers 10086 (Series), is an example of a basic manual, because many ratings use it for reference.

Rate Training Manuals are revised as required to keep them up to date technically. The revision of a Rate Training Manual is identified by a letter following the NavTra or NavPers number. You can tell whether any particular copy of a Rate Training Manual is the latest edition by checking the NavTra or NavPers number and the letter following this number in the most recent edition of List of Training Manuals and Correspondence Courses, NavTra 10061 (Series). (NavTra 10061 is actually a catalog that lists current training manuals and nonresident career courses; you will find this catalog useful in planning your study program.)

Rate Training Manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this manual and other Navy training publications when you are preparing for advancement.

1. Study the military requirements and the professional qualifications for your rate before you study the training manual. and refer to the "quals" frequently as you study. Remember, you are studying the training manual in order to meet these "quals."

2. Set up a regular study plan. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the training manual intensively, become familiar with the entire manual. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the manual without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

4. Look at the training manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a clear picture of the scope and content of the manual. As you look through the manual in this way, ask yourself some questions: What do I need to learn about this? What do I already know about this? How is this information related to information given in other chapters? How is this information related to the qualifications for advancement?

5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit–it may be a chapter, a section of a chapter, or a subsection. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit–chapter, section, or subsection–write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without referring to the training manual, write down the main ideas that you have learned from studying this unit. Do not quote the manual. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use Nonresident Career Courses whenever you can. The nonresident career courses are based on Rate Training Manuals or on other appropriate texts. As mentioned before, completion of a mandatory Rate Training Manual can be accomplished by passing its associated correspondence course. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training manuals. Taking a nonresident career course helps you to master the information given in the training manual, and also helps you see how much you have learned.

10. Think of your future as you study Rate Training Manuals. You are working for advancement to third class or second class right now, but someday you will be working toward higher rates. Anything extra that you can learn now will help you.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications described in this manual are subject to change or revision from time to time–some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you perform efficiently or to advance; it is likely to be a waste of time, and may even be seriously misleading.

CHAPTER 2

PUBLICATIONS, DRAWINGS, AND SCHEMATICS

There are many publications utilized in the proper maintenance of avionics systems. The systems in modern day aircraft have become so complex that maintenance is practically impossible without the use of technical publications. Even a mere listing of the electronics equipment carried on some of the more modern aircraft would be quite lengthy. It is impossible for any one person to be thoroughly familiar with all the various types of electronics equipment in present use; but with a good general background of electronic principles and circuit theory, a little study will enable the technician to rapidly familiarize himself with any specific equipment.

The purpose of this chapter is to discuss some of the sources of information available to the technician, how to use these references, and how to locate details on items of information and technician needs in the performance of his duties. Included in this chapter are discussions of publications, both general and specific; drawings and schematics, including illustrations, block diagrams, and wiring and cabling diagrams; charts and tables.

TECHNICAL PUBLICATIONS

Naval publications are important sources of information for guiding personnel of the naval aeronautic organization. Generally, these publications fall into two broad groups—those dealing with operational and administrative matters, and those dealing with technical and material matters.

The Secretary of Defense approved a reorganization of the Department of the Navy, which was effective 1 May 1966. This reorganization increases the breadth of authority and responsibility of the Chief of Naval Operations under the continuing direction of the Secretary of the Navy.

The Chief of Naval Operations has four major commands under him—BuPers, BuMed, Chief of Naval Material, and Chief of Naval Training.

The Chief of Naval Material heads the Naval Material Command which consists of the following six commands:

1. Naval Air Systems Command.
2. Naval Electronic Systems Command.
3. Naval Ship Systems Command.
4. Naval Ordnance Systems Command.
5. Naval Supply Systems Command.
6. Naval Facilities Engineering Command.

Each of the above commands is headed by a Commander; i.e., Commander, Naval Air Systems Command.

Concurrent with the establishment of the Naval Material Command, the following office and bureaus were abolished:

1. Office of Chief of Naval Material.
2. Bureau of Naval Weapons.
3. Bureau of Ships.
4. Bureau of Supplies and Accounts.
5. Bureau of Yards and Docks.

The Naval Air Systems Command is currently issuing its own directives and incorporating pertinent material now in BuWeps directives. BuWeps directives and instructions will continue to be used and referred to in training manuals for sometime to come even though the Bureau of Naval Weapons has been replaced by the Naval Air Systems Command.

Publications dealing primarily with the operation and maintenance of aircraft and related equipment within the Naval Establishment originating from the Naval Air Systems Command are issued by authority of the Commander, Naval Air Systems Command.

Publications concerned mainly with the training of flight personnel and air operations emanate from the Office of the Deputy Chief of Naval Operations (AIR).

The Naval Air Technical Services Facility functions as the sponsor of both types of publications and controls the initial distribution, distribution lists, printing, and retention of reproducible copy.

The Forms and Publications Supply Office functions as inventory manager for residual stocks of both types of publications, including the supporting distribution system and numerical cataloging.

The basic sources of technical aeronautic information are the technical manuals (formerly called handbooks) issued by the Naval Air Systems Command. Letter publications usually supplement the information contained in aeronautic technical manuals.

Technicians at the E-4 and E-5 levels are primarily concerned with technical publications; therefore, this discussion is directed mainly toward them. However, it includes some coverage of general and administrative type publications of importance to all naval personnel.

Good technical manuals are vital to the maintenance of modern weapons systems. Our Navy's combat readiness depends, to an increasing degree, on the information and knowledge possessed by maintenance personnel. If these men are to maintain increasingly complex weapons systems, incorporating the latest devices and systems, they must be able to obtain the required information from technical manuals.

The Department of Defense, the Department of the Navy, and the Naval Air Systems Command are working together to improve the standardization and quality of aeronautic maintenance manuals. The purpose of the following discussion is to present some detailed information concerning the contents and uses of these manuals.

NAVAL AERONAUTIC PUBLICATIONS INDEX

All aeronautic publications are assigned a title and code number. When they are available for issue, all publications, except Instructions and Notices, are listed in the Naval Aeronautic Publications Index (NAPI).

A complete Naval Aeronautic Publications Index consists of several individual publications, each of which serves a specific purpose. They are identified as follows:

Navy Stock List of Forms and Publications, NavSup Publication 2002, Section VIII, Parts C and D.

Equipment Applicability List, NavAir 00-500A.

Aircraft Application List, NavAir 00-500B.

Directives Application List by Aircraft Configuration, NavAir 00-500C.

Letter Type Technical Directives Equipment and Subject Applicability List, NavAir 00-500D.

A description of these lists and their uses is presented in the following paragraphs.

Navy Stock List of Forms and Publications

The Navy Stock List (NSL) of Forms and Publications (NavSup 2002) is a 13-section index of all the forms and publications used throughout the Navy and stocked by the Naval Supply Systems Command. Section VIII of this Stock List contains Naval Air Systems Command publications. This section is made up of four parts—A, B, C, and D. Parts A and B pertain to ordnance publications. Part C and Part D make up one part of the Naval Aeronautic Publications Index. Part C is the numerical listing of manual type aeronautic technical publications, and Part D is the numerical listing of letter type publications. These two parts—C and D—are referred to as the Numerical Sequence List or Numerical Index of the Naval Aeronautic Publications Index.

Part C (manual publications) is divided into subject matter groups, and all publications within a group are then listed in numerical order. For example, all manuals in the 00 series are listed first, then followed by the 01, 02, 03, etc., through the 51 series. The listing includes the publication code number, stock number, title, date of latest issue or revision, security classification, and requisition restriction code.

Part D is further divided into a number of subsections. Some of these include general, aircraft/airframe, accessories, powerplants, and support equipment. Listed in the general section are Aircrew System Bulletins and Changes, Aviation Clothing and Survival Equipment Bulletins and Changes, Technical Orders, and Technical Notes. All Aircraft/Airframe Changes and Bulletins are listed in the aircraft/airframe section. The accessories section contains a listing of all Accessory Changes and Bulletins. Engine Bulletins and Changes are listed in the powerplants section. The support equipment section contains a listing of all Support Equipment Changes and Bulletins.

The basic index (NavSup Publication 2002, Section VIII, Parts C and D) is revised and reissued annually. A separate supplement covering each Part is issued bimonthly between issues. The revision to the basic index, as well as each supplement, is cumulative from the prior revision.

Although the other parts of the Naval Aeronautic Publications Index (discussed in the following paragraphs) must be used to identify and locate publications, by code number, available for specific items of equipment and to check the applicability of publications to specific equipment, the Numerical Index must be used to completely identify and to order required publications. When an applicable publication number is found in one of the other parts of the NAPI, it can be easily located in the Numberical Index. Here it can be more completely identified as to title and nomenclature, stock number (for manual type publications), security classification, and any restrictions concerning the requisitioning of the publication. In addition, the date of the latest revision or issue of the publication is listed. This provides a means whereby the issue and/or revision dates of the publications on hand in an activity can be checked against the dates listed in the current issue and supplement of the Numerical Index, thus assuring that the publications are current.

Equipment Applicability List

Basically, the Equipment Applicability List, NavAir 00-500A, is a cross-reference index listing of NavAir manual type publications according to model/type part number. Since this index contains several thousand entries, one document would be very cumbersome to use. For this reason, this Index is divided into several volumes. At the time of this writing, there are seven volumes. Each of the first six volumes contains 400 pages and Volume 7 contains the remaining entries. With the exception of several small sections in the first part of Volume 1, the Equipment Applicability List is one continuous index of model/type part numbers listed in strict alphanumerical sequence. In addition to an introduction, the other sections in the first part of Volume 1 pertain primarily to manuals for aircraft, weapons systems, and aircraft engines. Therefore, the publication numbers are listed according to aircraft, aircraft engine, and weapons system designation.

Publication numbers may appear in this Index more than once, inasmuch as complete equipment systems and their respective major components are listed separately.

This list should be used when attempting to determine what publications are available on a particular item of equipment, and the class of equipment, model, type, or part number are known.

This list is revised and reissued annually. It is kept current by the issuance of quarterly cumulative supplements.

Aircraft Application List

The Aircraft Application List (NavAir 00-500B) contains a listing of all manuals grouped according to their application to an aircraft. This part of the index does not contain listings of any letter type publications, and all manuals are listed by publication code number only.

A list of basic numbering categories is provided in the front of the book. This list may be used in determining the general type of equipment covered in a publication. It may also be used to determine what manuals are available for a particular model of aircraft.

This list is revised and reissued semiannually, in March and September and is not supplemented between reissues.

Directives Application List by Aircraft Configuration

The Directives Application List by Aircraft Configuration (NavAir 00-500C) contains a listing of the active NavAirSysCom letter type technical directives with respect to their applicability to aircraft. The lists in this volume are arranged first by aircraft series, second by aircraft configuration, and third by Airframe/Aircraft Bulletin and/or Change numbers. NOTE: Configuration refers to modifications made to a basic aircraft model. For instance, F-4A, F-4B, RF-4B, F-4G, etc., are all different configurations of the F-4 aircraft model.

This list is revised and reissued semiannually, in January and July and is not supplemented between reissues.

Equipment and Subject Applicability List

The Equipment and Subject Applicability List (NavAir 00-500D) is a relatively recent addition to the NAPI. It contains a cross-reference index listing of Naval Air Systems Command letter type technical directives (Bulletins and Changes). It serves the same purpose for letter type technical directives as the Equipment Applicability List (NavAir 00-500A) does for technical manuals. However, since the NavAir 00-500D lists only those model/type part numbers for which technical directives have been issued, it is much smaller than the NavAir 00-500A. The complete List is contained in one volume but is divided into two parts. Part A is the Equipment Index and Part B is the Subject Index.

Part A contains a listing of all Naval Air Systems Command letter type technical directives on aircraft components and related equipment by model, type, and part number. Each number is listed in alphanumerical sequence within its cognizant equipment series.

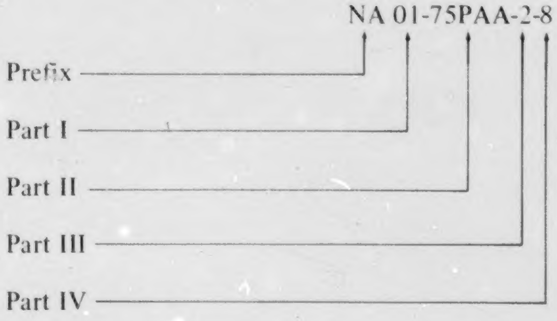
Part B contains a listing of Naval Air Systems Command letter type technical directives by subject, arranged in the following manner:

1. Prime System.
2. Component part of the system.
3. Airframe Title, Bulletin/Change Number.

NUMBERING SYSTEM FOR MANUALS

Publications issued by the Naval Air Systems Command are designated according to a numbering system based on the type publication and its material content. The system cannot be described fully in this manual because of its complex nature and many exceptions.

Coded designations assigned to technical manuals consist of a prefix and an alphanumeric sequence of three or four parts. The example shown below will be used to explain the system for designation of technical manuals:



Prefix

The prefix may consist of the letters NavAir (NA), NavAer (NA), NavWeps (NW), AN, TO, or CO. NavAer and NavWeps publications were issued by the Bureau of Aeronautics and Bureau of Naval Weapons, respectively. All new publications are designated with the NavAir (NA) prefix.

The prefix AN was previously assigned for technical manuals used jointly by the Navy and the Air Force; they were prepared to coordinate military specifications.

TO was the prefix assigned to technical manuals originated by the Air Force.

CO was previously used to designate a technical manual with a Confidential security classification.

These prefixes, while no longer assigned for new material, will remain in effect for existing assignments until superseded.

Part I

Part I consists of numbers to identify the general subject classification with the basic subject to which they pertain. These numbers usually have two digits; however, when an additional classification breakdown is necessary, Part I consists of two digits followed by a letter. An example of this is found in the 02 (Powerplants) series. A typical entry in this series has the number 02B immediately following the prefix NA. In this example, the B identifies the powerplant as a jet propulsion type.

Table 2-1 lists the general subject categories and their numerical equivalent. In some instances, it will be noted that an equipment category has more than one numerical equivalent. In the case of electronics, which carries the codes 08 and 16, the equipment category is in the process of subdivision or change.

Part II

Part II of the publication number consists of numbers (or numbers and letters) and indicates the specific class, group, type, or model and manufacturer of the equipment. The subject breakdowns are listed at the beginning of each separate major division within NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part C.

Table 2-1.—Subject categories and code numbers for aeronautic manuals.

General	00
Allowance lists	00-35Q
Training publications (aviation)	00-80
Aircraft	01
Powerplants	02
Accessories	03
Hardware and rubber	04
Instruments	05
Fuels, lubricants, and gases	06
Dopes and paints	07
Photography	10
Aviation armament	11
Fuel and oil handling equipment	12
Parachute and personal equipment	13
Standard preservation and packaging instructions	15
Electronics	08 & 16
Machinery, tools, and test equipment	17 & 18
Ground servicing and automotive equipment	19
Descriptive data for aviation support equipment	20
Chemical equipment	24
Instructional equipment and training aids	09 & 28
Meteorology (aerology)	50
Ships installations	51

For aircraft manuals and equipment manuals, this part will be explained in more detail later.

Part III

Part III consists of a number or numbers which designate a specific manual. For airframes and engines, this part designates a specific type manual. For other types of equipment, this part is assigned in numerical sequence and has no direct reference to the type of manual.

Part IV

Part IV pertains only to certain specific classes of manuals (such as the Maintenance Instructions Manuals for aircraft), and designates a particular manual of a set. Numbering is not completely standardized, and may have decimal or even double decimal suffixes. The exact volume desired may be determined from the lists or indexes of publications.

AIRCRAFT MANUALS

Aircraft manuals are prepared by the manufacturer and published for each aircraft model in naval use. The manual for a particular aircraft model consists of a series of individual publications, each dealing with a definite phase of the overall operation or maintenance program. As indicated in the preceding discussion, aircraft manuals fall into the 01 - series category, and manuals pertaining to a particular model may be identified by an alphanumeric designator immediately following the 01 -

01 - Series Manuals

Aircraft technical manuals are of several different types, some of which are of extreme importance to the maintenance technician in the routine performance of his normal duties. These types are discussed in some detail in this chapter. Manuals of some other types are of limited importance to avionics personnel, and are discussed only briefly.

Using the previous example of manual designation, the aircraft model to which a manual applies may be determined from Part II of the designator. The numbers are coded to indicate the specific manufacturer, and the letters indicate the particular aircraft model.

GENERAL AIRCRAFT MANUALS.–The 01-1 series manuals do not apply to specific aircraft, but present some aspect of construction, operation, maintenance, repair, or inspection applicable to many models of aircraft. Some important examples of this type manual are NavAir 01-1A-505 (Installation Practices: Aircraft Electric and Electronics Wiring); NavAir 01-1A-509 (Aircraft Cleaning and Corrosion Control for Organizational and Intermediate Maintenance levels).

FLIGHT MANUALS.–Manuals of this class are identified by the number 1 in Part III of the standard nomenclature. For a given model aircraft, the complete flight manual usually comprises the standard NATOPS manual, pocket checklist, and classified supplements. Although this series is of primary interest to the pilot and aircrew, much of the information is of general interest to all personnel concerned in any manner with that aircraft. One section of special interest to avionics personnel is the functional operation of the electronics equipment installed.

STRUCTURAL REPAIR.–Structural Repair Manuals (identified by the number 3 in Part III of the standard nomenclature) usually comprise two manuals. The -3-1 manual is for use by organizational and intermediate level maintenance activities, while the -3-2 manual is for use by depot level maintenance activities. These manuals prescribe procedures and methods for making repairs to structural components of the aircraft.

MISCELLANEOUS MANUALS.–Although the contents of most other aircraft manuals are standardized, the numbering system is not. Some typical examples are the Special Weapons Check List, Special Stores, Assembly Procedures (for guided missile and target aircraft), Source Coded Data, Component and Shop Repair Data, etc. Some aircraft have only a few manuals of this type; others have many.

Maintenance Instructions Manual (MIM)

For this type manual, Part III of the standard designator is the number 2. The MIM comprises a variable number of individual publications, each dealing with some portion of the overall maintenance effort for the applicable model aircraft. The MIM (formerly called Handbooks of Maintenance Instructions) provides information concerning the location, function, operation, removal, installation, testing, adjusting, and troubleshooting of components. Maintenance methods recommended are concerned with procedures such as those which can be performed by an operating squadron.

These manuals provide the technician with an invaluable aid in locating equipment components and interconnecting cables in the aircraft, and for inspection purposes as well as troubleshooting.

Before attempting any new task on an aircraft, the Maintenance Instructions Manual for that particular aircraft should be consulted. By proper use of this manual, possible damage may be prevented and much time may be saved. Recommended maintenance methods are concerned with procedures which can be accomplished by operating units, and include a Quality Assurance Summary, which indicates the minimum quality control inspection requirements for each maintenance task.

In the past, these manuals were issued as a single complete unit. They were arranged so that the pertinent sections could be removed and kept available in the shop. At present, the separate sections of these manuals are being issued as separate publications under individual identifying numbers. This facilitates procurement, storage, filing, and use of specific parts of the manual by maintenance personnel.

Avionics maintenance personnel are concerned most often with the sections covering electrical and electronic systems, radio and radar, and wiring data.

NUMBER BREAKDOWN.–Part IV of the standard designator for an aircraft Maintenance Instructions Manual indicates the subject content of the manual. This designator may consist of a single number, a number and decimal, or even a number with double decimals, as required to break down the information sufficiently. Due to the differences in operational usage of various models of aircraft, this system cannot be standardized completely. However, the following partial listing is typical for many of the new aircraft:

-2–Airframe Maintenance Instructions Manual
  - -0–Maintenance Planning Data (For some models of aircraft, this data is contained in a -100 publication rather than in -2-0.)
  - -1.1–General Information and Servicing
  - -1.2–Corrosion Control and Decontamination
  - -2–Airframe Systems
  - -3–Powerplant and Related Systems
  - -4–Instrument Systems
  - -5–Electrical Systems
  - -5.1–Electrical Power Supply System
  - -5.2–Lighting System
  - -6–Electronic Systems
  - -7–Armament and Related Systems
  - -8–Airborne Missile Control Systems
  - -9–Systems Integration
  - -10–Wiring Diagrams
  - -10.1–Wiring Data Diagrams
  - -10.2–Wiring Data Repair

Each category may be broken down into single or double decimal subdivisions as the occasion requires.

MANUAL BREAKDOWN.–The typical volume of the MIM contains six sections as follows:

Section I–Introduction. Provides a general description of the manual, including the scope of coverage, format, and arrangement of the included information. It contains listings of applicable publications and technical directives required by operating activities pertaining to the specific model aircraft or equipment covered in the manual.

Section II–Description and Operation. Includes a physical description of the aircraft or equipment covered by the manual. It includes a detailed listing of components, with separate tables for equipment components, tube and transistor complements, and fuses and circuit breakers. For equipments, this section also incorporates detailed information regarding input and output characteristics and requirements and operating instructions. Also included is a brief discussion on the theory of operation, definition of terms, explanation of terms and symbols, simplified and partial functional diagrams, and built-in test features.

Section III–Organization Maintenance (Line and Hangar). Presents information on testing and operational checks on the various systems or components covered in the manual. It includes such information as a tools and equipment list, manpower requirements, and test procedures (with pertinent notes, warnings, and cautions). In addition, this section includes system troubleshooting charts for installed equipment, and instructions for removal and installation of the equipment.

Sections IV and V–Intermediate Maintenance (Component Repair) (Section V is not always included.) Some manuals combine all functions of maintenance into a single publication; others have various breakdowns. When this level of maintenance is included, the detailed contents parallel those of Section IV, except that the procedures for individual components (rather than the complete unit), are discussed.

Section VI–Diagrams. Contains the complete set of wiring and schematic diagrams for those units covered in the manual.

Illustrated Parts Breakdown (IPB)

The Illustrated Parts Breakdown normally consists of several individual manuals: one for each major functional element of the aircraft, and a final volume which is an index. It is identified by the -4 following the aircraft designation in the standardized publication identification system. It is useful in the procurement, requisitioning, storing, issuing, and identification of new or reclaimed parts.

It can also be used to determine the exact part or item required for replacement in a repair situation. It can also be used as a guide in reassembly of units which have been disassembled for testing, cleaning, or repair.

The separation of the IPB into its separate manuals does not necessarily follow the same order as the MIM breakdown; however, the type information available is consistent for nearly all IPB's.

MANUAL BREAKDOWN.–With the exception of the Index volume, each volume of the IPB follows generally the same format. It is divided into two sections–Introduction and Group Assembly Parts List.

Section I–Introduction. Contains specific detailed instructions for use of the particular IPB and the set to which it belongs.

Section II–Group Assembly Parts List. Provides reference and identification data for the various assemblies and subassemblies within the scope of the manual. For each assembly and subassembly, the data consists of a diagram and table. (See figs. 2-1 and 2-2.) The diagram indicates the location and general appearance of the item and provides clues for assembling.

Inserts A, B, C, and D illustrate items which are furnished as subassemblies of the major item. In the "description" column of the table, note the progressive indentations. The first entry is the complete assembly, and is begun flush at the left. Index numbers 1 through 15 refer to individual items of material which are parts of the assembly, and are indented one space. Index numbers 16 through 30 are bits and pieces of subassembly D and are indented two spaces. Further disassembly would be indicated by additional breakdown of one of the subassemblies, and the parts descriptions would be progressively indented in the table.

Note also the system used to identify attaching parts. Index number 9 is a cover, and the attaching parts are indexed as 10 and 11. This shows that these two items are used separately to attach 9 to the assembly. Sometimes a screw, washer, and nut (set) will be listed as a single item having a single index number. In these cases, the individual parts are still identified and described in the table. An example of this is index number 15. In each case, the words "attaching parts" preceded and followed by slant marks are inserted in the table immediately following the item they are used to attach.

The table furnishes the details regarding the bits and pieces which make up the unit. It is divided into five columns.

Column 1 gives the figure and index number. This number is a three-part sequence with hyphens separating the parts. The first part references the volume or major subdivision of the IPB. The second part indicates the number of the figure referenced. The third part indicates the callout number of the specific piece to which the other information pertains. The first entry always indicates the complete subassembly, and does not normally include the third part of the sequence.

Column 2 gives the part number for the specific item. This part number is used in conjunction with the Index volume of the IPB for stock number identification.

Column 3–Description. Provides the item name, manufacturer's code number (identifiable in the vendor's listing included in Section I), specification drawings, additional breakdown reference figures, and other pertinent data.

Column 4–Units Per Assembly. Specifies the total number of a given item in a single assembly.

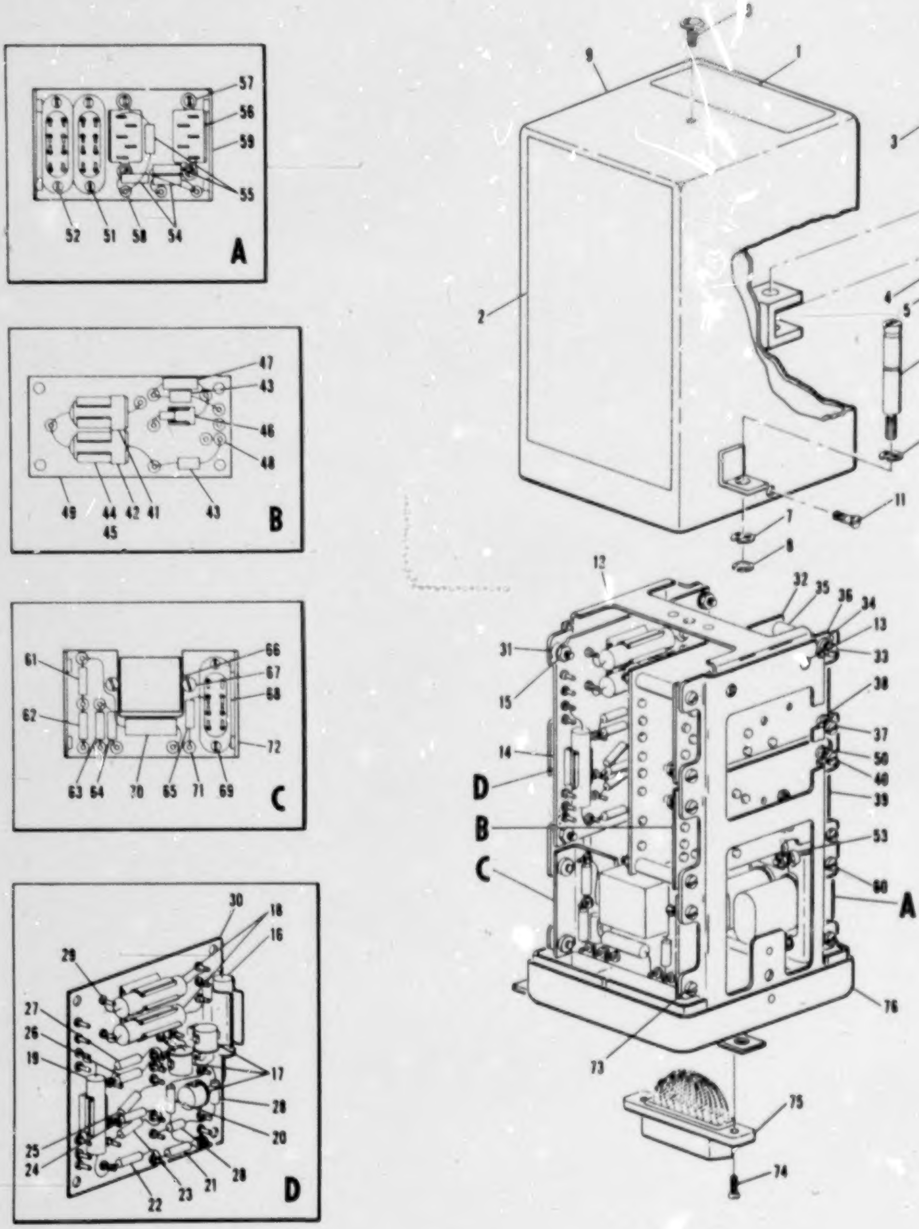
Column 5–Usable on Code. When a specific item is used on certain aircraft of a given model, and a different item is used on other aircraft of the same hotel, this column is used. When all models use the same item, this column is left blank. The coding is explained in the Introduction, Section I.

The first figure of each volumn is normally of the aircraft, showing the location of the major items of the aircraft. The callout numbers are referenced in the accompanying table, and are crossindexed with the applicable IPB figure number; this table gives no details except the title of the item or assembly. This figure and table are actually included in the Introduction, Section I.

INDEX BREAKDOWN.–The Index volume of the IPB comprises three sections–Introduction, Numerical Index, and Reference Designation Index.

Section I–Introduction. Contains details on the contents and arrangement of the volume.

Section II–Numerical Index. Consists of a numerical index containing all items listed in the Group Assembly Parts Lists of the preceding volumes. It is divided into two parts: The first part lists all the contractor part numbers, and the second part lists all the standard and vendor part numbers. Each part of the section is divided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AT.16

Figure 2-1.—IPB, sample figure.

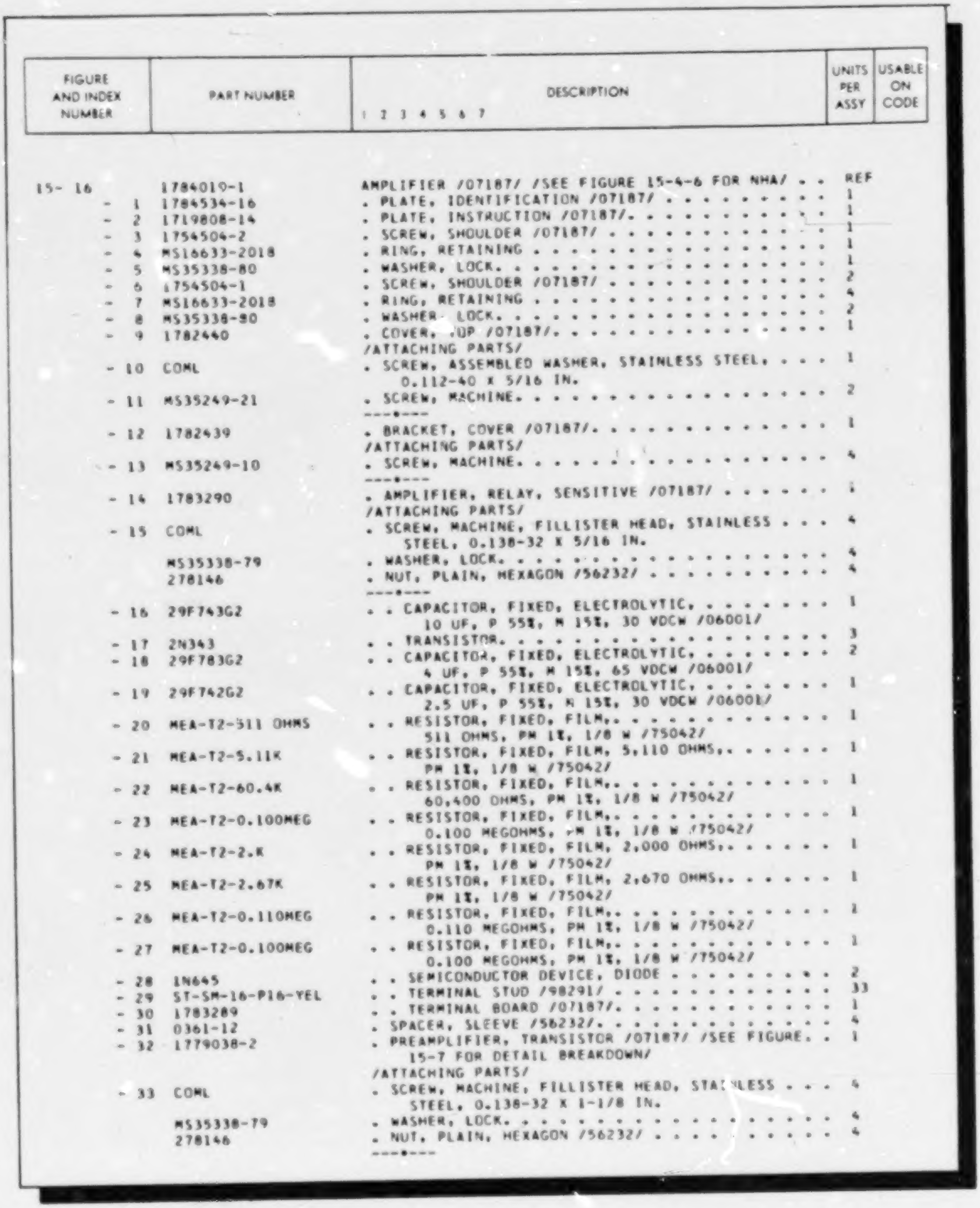

FIGURE AND INDEX NUMBER	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASSY	USABLE ON CODE
15- 16	1784019-1	AMPLIFIER /07187/ /SEE FIGURE 15-4-6 FOR NHA/ . .	REF	
- 1	1784534-16	. PLATE, IDENTIFICATION /07187/	1	
- 2	1719808-14	. PLATE, INSTRUCTION /07187/.	1	
- 3	1754504-2	. SCREW, SHOULDER /07187/	1	
- 4	MS16633-2018	. RING, RETAINING	1	
- 5	MS35338-80	. WASHER, LOCK.	1	
- 6	1754504-1	. SCREW, SHOULDER /07187/	2	
- 7	MS16633-2018	. RING, RETAINING	4	
- 8	MS35338-80	. WASHER, LOCK.	2	
- 9	1782440	. COVER, TOP /07187/.	1	
		/ATTACHING PARTS/		
- 10	COML	. SCREW, ASSEMBLED WASHER, STAINLESS STEEL, . . . 0.112-40 X 5/16 IN.	1	
- 11	MS35249-21	. SCREW, MACHINE.	2	
		---*---		
- 12	1782439	. BRACKET, COVER /07187/.	1	
		/ATTACHING PARTS/		
- 13	MS35249-10	. SCREW, MACHINE.	4	
		---*---		
- 14	1783290	. AMPLIFIER, RELAY, SENSITIVE /07187/	1	
		/ATTACHING PARTS/		
- 15	COML	. SCREW, MACHINE, FILLISTER HEAD, STAINLESS . . . STEEL, 0.138-32 X 5/16 IN.	4	
	MS35338-79	. WASHER, LOCK.	4	
	278146	. NUT, PLAIN, HEXAGON /56232/	4	
		---*---		
- 16	29F743G2	. . CAPACITOR, FIXED, ELECTROLYTIC, ... 10 UF, P 55%, M 15%, 30 VDCW /06001/	1	
- 17	2N343	. . TRANSISTOR.	3	
- 18	29F783G2	. . CAPACITOR, FIXED, ELECTROLYTIC, ... 4 UF, P 55%, M 15%, 65 VDCW /06001/	2	
- 19	29F742G2	. . CAPACITOR, FIXED, ELECTROLYTIC, ... 2.5 UF, P 55%, M 15%, 30 VDCW /06001/	1	
- 20	MEA-T2-511 OHMS	. . RESISTOR, FIXED, FILM,. . . . . 511 OHMS, PM 1%, 1/8 W /75042/	1	
- 21	MEA-T2-5.11K	. . RESISTOR, FIXED, FILM, 5,110 OHMS,. . . . . . . PM 1%, 1/8 W /75042/	1	
- 22	MEA-T2-60.4K	. . RESISTOR, FIXED, FILM,. . . . . 60,400 OHMS, PM 1%, 1/8 W /75042/	1	
- 23	MEA-T2-0.100MEG	. . RESISTOR, FIXED, FILM,. . . . . 0.100 MEGOHMS, PM 1%, 1/8 W /75042/	1	
- 24	MEA-T2-2.K	. . RESISTOR, FIXED, FILM, 2,000 OHMS,. . . . . . . PM 1%, 1/8 W /75042/	1	
- 25	MEA-T2-2.67K	. . RESISTOR, FIXED, FILM, 2,670 OHMS,. . . . . . . PM 1%, 1/8 W /75042/	1	
- 26	MEA-T2-0.110MEG	. . RESISTOR, FIXED, FILM,. . . . . 0.110 MEGOHMS, PM 1%, 1/8 W /75042/	1	
- 27	MEA-T2-0.100MEG	. . RESISTOR, FIXED, FILM,. . . . . 0.100 MEGOHMS, PM 1%, 1/8 W /75042/	1	
- 28	1N645	. . SEMICONDUCTOR DEVICE, DIODE	2	
- 29	ST-SM-16-P16-YEL	. . TERMINAL STUD /98291/	33	
- 30	1783289	. . TERMINAL BOARD /07187/.	1	
- 31	0361-12	. SPACER, SLEEVE /56232/.	4	
- 32	1779038-2	. PREAMPLIFIER, TRANSISTOR /07187/ /SEE FIGURE. . 15-7 FOR DETAIL BREAKDOWN/	1	
		/ATTACHING PARTS/		
- 33	COML	. SCREW, MACHINE, FILLISTER HEAD, STAINLESS . . . STEEL, 0.138-32 X 1-1/8 IN.	4	
	MS35338-79	. WASHER, LOCK.	4	
	278146	. NUT, PLAIN, HEXAGON /56232/	4	
		---*---		

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Figure 2-2.—IPB, corresponding table.

into five columns: Part Number, Federal Stock Number, Volume Figure and Index Number, Source Code, and Accountability/Recovery Code.

Section III–Reference Designation Index. Provides a cross reference between the Reference Designation Number assigned to each item of electrical, electronics, or mechanical equipment and the part number for each such item. Reference designation numbers for each of the items of equipment are determined from the applicable section of the MIM.

USING THE IPB.–In order to derive maximum benefit from maintenance functions, certain records and reports must be compiled. The requirements for these vary somewhat in different type squadrons and in different areas. The reports and records required in each activity are determined by the maintenance supervisor as one of his administrative duties. One type report that is universally required is the Unsatisfactory Material/Condition Report. This and other reports and records require details concerning parts that have failed or that have been replaced for any reason. These details are available from the IPB. The procedures for locating the information depends on what is known about the part and what data is required, as shown in the following discussion:

1. When the part number is not known, determine the function and application of the part. Turn to the Table of Contents of the IPB volume containing the affected equipment or system and select the title that seems most appropriate. Note the illustration page number. Turn to the page indicated and locate the desired part on the illustration. From the illustration, obtain the index (callout) number assigned to the part. Refer to the accompanying description for specific information regarding the part. (If the Federal Stock Number is desired, next refer to the Index volume of the IPB. Locate the part number and note the FSN.)

2. When only the part number is known, refer to the Numerical Index. Locate the part number and note the figure and index number assigned to the part. Turn to the figure indicated, and locate the referenced index number. If a pictorial representation of the part or its location is desired, refer to the same index number on the accompanying illustration. If the FSN is desired, it may be determined directly from the Index volume by locating the part number.

3. When only the reference designation is known, refer to the Reference Designation Index. Locate the reference designation and note the figure and index number and the part number assigned. Turn to the figure indicated and locate the index number. If a pictorial representation of the part, or its location is desired, refer to the index number shown on the accompanying illustration.

Periodic Maintenance Requirements Manual (PMRM)

Periodic maintenance requirements for a particular model aircraft are contained in the -6 series of publications for that model aircraft. The series includes (in addition to the Periodic Maintenance Requirements Manual) the cards and charts used to plan and control the progress of work in scheduled maintenance actions. They provide step by step procedures for performing the minimum inspections required for each type of scheduled maintenance action.

EQUIPMENT MANUALS

Most items of electronics equipment or test equipment commonly used in naval aviation are covered by a manual or a series of manuals. These manuals are usually prepared by the contractor and distributed by the Naval Air Systems Command. Standardization has not progressed to the same extent as it has in the aircraft manuals; however, some generalizations hold true for most manuals of this group.

08- Series

Manuals of this category usually apply to older equipments which still may be in use. The 08- series is at present undergoing a complete reorganization and is being combined with the 16- series for electronics equipment.

16- Series

Manuals of this series are identified by a numbering system similar to that used with the

Table 2-2.—16-Series breakdown.

Subseries	Classification
1	General
5Q	Radio
5S	Radar
30	Joint Nomenclature Radio Equipment
35	Joint Nomenclature Radio Components
40	Signal Corps Nomenclature Equipment
45	Commercial British and Navy Radio Equipment
50	Automatic & Semiautomatic Electronic Checkout Equipment
55	Radio, Radar, Electronic, and Spare Parts Lists

aircraft manuals, consisting of a three-part designation following a prefix. The prefix and the Part I serve the same purpose and follow the same rules as outlined in the preceding section. Parts II and III are not completely standardized except for subsections 30 and 35. The subdivisions of the 16- series are listed in table 2-2.

GENERAL.—The 16-1 Series manuals include several publications of many types, the contents of which do not permit inclusion in any other subseries. They include manuals pertaining to general maintenance practices, training manuals, design guidance data, etc. Some of these manuals have been individually referenced in this chapter; some others are referenced in the current indexes of publications.

RADIO AND RADAR.—Manuals of the 5Q and 5S subseries pertain to older equipments and the manuals do not conform to present standardization format. They include miscellaneous operation and maintenance data for radio and radar equipments.

JOINT NOMENCLATURE RADIO EQUIPMENT.—Manuals of this subseries normally appear in the standard format. Part II of the identifying designator specifies the equipment to which the manual applies; Part III specifies the type manual. Although Part III is not completely standardized, the number refers to the following type manuals:

Operation Instructions
Service Instructions
Overhaul Instructions
Illustrated Parts Breakdown

Many smaller and less complicated equipments combine two or more of these manuals into one volume, but each of the above manuals will be discussed separately in a later section of this chapter.

OTHER SUBSERIES.—Manuals of the 35 subseries are basically the same as those of the 30 subseries, except that they deal with components rather than complete equipments. Manuals of the 40, 45, 50, and 55 subseries cannot be readily identified as to equipment applicability.

Equipment Nomenclature System

The Joint Communication—Electronic Nomenclature System ("AN" System), formerly known as the Joint Army-Navy Nomenclature System, is designed so that its indicators will tell at a glance many things pertinent to the item. For example, it tells whether the item is a set or a component, and such other information as where it is used, the kind of equipment, and its purpose.

An indicator for a complete set begins with the letters AN. This is followed by a slant bar and a three-letter group. The three letters of the second group give the general nature of the installation, the type of equipment, and the purpose of the equipment, respectively. Following the three-letter group is a number which indicates the specific model of the equipment. An example of the basic designation is

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AN/ARC-38. As can be seen in table 2-3, the letters following the slant bar mean airborne radio communications.

When the system just described is applied to a unit of the complete set, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of the unit in question. For example, a control unit used with the AN/ARC-38 is designated C-1398/ARC-38. The letter C is an indicator letter which in this case means control. The number following C indicates the specific model of control box. Table 2-4 presents commonly used unit indicator letters that are used in the letter-number group.

Operation Instruction Manual

Operation Instruction Manuals cover the operation of specific equipments and the necessary checks and adjustments required for optimum performance. These instructions are written from the equipment operator's viewpoint and do not include all data vital to the maintenance technician.

Service Instruction Manual

The Service Instruction Manual contains information on maintenance and usage of specific equipment. It provides instructions for alining, maintaining, troubleshooting, and repairing the equipment, as well as concise tabular data on fuses, power drain, number of units, etc. Because of the quantity and complexity of the material involved, the manual is divided into several sections.

Section I, Description and Leading Particulars, gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of components and any special electrical or mechanical characteristics of the system or components.

Section II, Special Test Equipment and Special Tools, lists all necessary special test equipment and tools (including test racks) which are used for complete bench testing of the system or the components. Any instructions necessary for modifying the test equipment for special use or for the fabrication of a special test harness are also found in this section.

Section III, Preparation for Use and Reshipment, is divided systematically, showing the method by which the equipment should be handled from the time it is received until it is ready for use by the operator. The section contains general information on uncrating and assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the components are also included. Applicable data on any checks and adjustments required during installation of the equipment is found in this section.

Section IV, Theory of Operation, presents a general description of the equipment first, and this is followed by the detailed explanations of the individual circuits. The general description is usually given from the viewpoint of circuit development (see the discussion later in this chapter concerning drawings and schematics), and block diagrams are used to trace the development path. The function of each unit is explained, as well as its relationship to other units in the equipment.

Section V, Organizational and Operational Maintenance, provides the instructions essential for the maintenance of the equipment by organizational maintenance personnel, and indicates the level of maintenance activities designated to perform it. Included are the preoperational and daily inspections and tests, the bench-test procedures, and the troubleshooting methods to be used by these activities. Each performance procedure in this section includes instructions essential for the proper use of test equipment in diagnosing a trouble within a specific equipment.

Section VI, Field Maintenance, includes the instructions required for servicing the equipment at the field maintenance levels. In addition to alinement and parts removal procedures, information is given for checking component functions by means of performance checks. Also contained in this section are systematic trouble isolation procedures which assist in localizing a defective part or component to a circuit or group of circuits, depending upon the nature of

Table 2-3.—Set indicator letters.

First letter (Designed installation classes)	Second letter (Type of equipment)	Third letter (Purpose)
A - Piloted aircraft	A - Invisible light, heat radiation	A - Auxiliary assemblies (not complete operating sets used with or part of two or more sets or sets series)
B - Underwater mobile, submarine	B - Pigeon (do not use)	B - Bombing
C - Air transportable (inactivated, do not use)	C - Carrier	C - Communications (receiving and transmitting
D - Pilotless carrier	D - Radiac	D - Direction finder, reconnaissance, and/or surveillance
F - Fixed ground	E - Nupac	E - Ejection and/or release
G - General ground use	*F - Photographic	G - Fire-control, or searchlight directing
K - Amphibious	G - Telegraph or teletype	H - Recording and/or reproducing (graphic, meteorological and sound)
M - Ground, mobile	I - Interphone and public address	K - Computing
P - Portable	J - Electromechanical or Inertial wire covered	L - Searchlight control (inactivated, use G)
S - Water surface	K - Telemetering	M - Maintenance and/or test assemblies (including tools)
T - Ground, transportable	L - Countermeasures	N - Navigational aids (including altimeters, beacons, compasses, racons, depth, sounding, approach, and landing)
U - General utility	M - Meteorological	P - Reproducing (inactivated, use H)
V - Ground, vehicular	N - Sound in air	Q - Special, or combination of purposes
W - Water surface and underwater combination	P - Radar	R - Receiving, passive detecting
	Q - Sonar and underwater sound	S - Detecting and/or range and bearing, search
	R - Radio	T - Transmitting
	S - Special types, magnetic, etc., or combinations of types	W - Automatic Flight or remote control
	T - Telephone (wire)	X - Identification and recognition
	V - Visual and visible light	
	W - Armament (peculiar to armament, not otherwise covered)	
	X - Facsimile or television	
	Y - Data processing	

*NOTE: Not for U.S. use except for assigning modification letters to previously type-designated items.

Table 2-4.—Unit indicator letters.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
AB	Supports, antenna	Antenna mounts, mast bases, most sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radio frequency, video, electronic control, etc.
AS	Antennae, simple and complex	Arrays, parabolic type, masthead, whip or telescopic loop, dipole, reflector, etc.
*AT	Antennae, simple	For new assignments use AS.
BA	Battery, primary type	B batteries, battery packs, etc.
BB	Battery, secondary type	Storage batteries, battery packs, etc.
BZ	Signal devices, audible	Buzzers, gongs, horns, etc.
C	Controls	Control box, remote tuning control, etc.
CA	Commutator assemblies, sonar	Peculiar to sonar equipment.
CB	Capacitor bank	Used as a power supply.
CG	Cable assemblies, R-F	R-F cables, waveguides, transmission lines, etc., with terminals.
CH	Chassis, drawer, door	A framework designed to accept plug-in modules. May include circuitry and/or receptacles. Does not include the plug-in module(s). It is not a storage facility or blank chassis.
CK	Crystal kits	A kit of crystals with holders.
CM	Comparators	Compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating regulating or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calculating device.
CR	Crystals	Crystal in crystal holder.
CU	Couplers	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic)	Electronic apparatus for changing the phase, frequency, or from "one" medium to "another."
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cable assemblies, non-R-F	Non-R-F cables with terminals, test leads, also composite cables of R-F and non-R-F conductors.
CY	Cases and cabinets	Rigid and semirigid structure for enclosing or carrying equipment.
D	Dispensers	Chaff, leaflet, flare, napalm, bomblet, etc.
DA	Load, dummy	R-F and non-R-F test loads.
DT	Detecting heads	Magnetic pickup device, search coil, hydrophone, etc. (see R-F).
DY	Dynamotors	Dynamotor power supply.
E	Hoists	Sonar hoist assembly, etc.
F	Filters	Bandpass, noise, telephone, wave traps, etc.
FN	Furniture	Chairs, desks, tables, etc.
FR	Frequency measuring device	Frequency meters, tuned cavity, etc.
G	Generators, power	Electrical power generators without prime movers, (see PU and PD).
GO	Goniometers	Goniometers of all types.
GP	Ground rods	Ground rods, stakes, etc.

Table 2-4.—Unit indicator letters—Continued.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
H	Head, hand, and chest sets	Includes earphone.
HC	Crystal holder	Crystal holder less crystal
HD	Environmental apparatus	Heating, cooling, dehumidifying, pressure, vacuum devices, etc.
ID	Indicators, noncathode-ray tube	Calibrated dials and meters, indicating lights, etc. (see IP).
IL	Insulators	Strain, standoff, feed-through, etc.
IM	Intensity measuring devices	Includes SWR gear, field intensity and noise meters, slotted lines, etc.
IP	Indicators, cathode-ray tube	Azimuth, elevation, panoramic, etc.
J	Junction devices	Junction, jack and terminal boxes, etc.
KY	Keying devices	Mechanical, electrical and electronic keyers, coders, interrupters, etc.
LC	Tools, line construction	Includes special apparatus such as cable plows, etc.
LS	Loudspeakers	Separately housed loudspeakers, intercommunication station.
M	Microphones	Radio, telephone, throat, hand, etc.
MA	Magazines	Magnetic tape or wire, etc.
MD	Modulators, demodulators, discriminators	Device for varying amplitude, frequency or phase.
ME	Meters	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MF	Magnets or magnetic field generators	Magnetic tape or wire eraser, electromagnet, permanent magnet, etc.
MK	Miscellaneous kits	Maintenance, modification, etc., except tool and crystal (see CK, TK).
ML	Meteorological devices	Barometer, hygrometer, themometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified, includes subassemblies. Do not use if better indicator is available.
MU	Memory units	Memory units.
O	Oscillators	Master frequency, blocking, multivibrators, etc. (for test oscillators, see SG).
**OA	Miscellaneous groups	Groups not otherwise classified. Do not use if a more specific indicator, such as OD, OE, OG, etc., applies.
**OB	Multiplexer and/or demultiplexer groups	Multiplexer groups, demultiplexer groups, composites thereof.
OC	Ocenographic devices	Bathythemographs, etc.
**OD	Indicator groups	All types.
**OE	Antenna groups	All types.
**OF	Adapter groups	All types.
**OG	Amplifier groups	All types.
**OH	Simulator groups	All types.
**OJ	Consoles and console groups	All types.
**OK	Control groups	All types.
**OL	Data analysis and data processing groups	All types.

Table 2-4.—Unit indicator letters—Continued.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
**OM	Modulator and/or demodulator groups	Modulator groups, demodulator groups, composites thereof.
**ON	Interconnecting groups	All types.
**OP	Power Supply groups	All types.
**OQ	Test Set groups	All types.
**OR	Receiver groups	All types.
OS	Oscilloscope, test	Test oscilloscopes for general test purposes.
**OT	Transmitter groups	All types.
**OU	Converter groups	All types.
**OV	Generator groups	All types excluding power generating equipment.
**OW	Terminal groups	Telegraph, telephone, radio, etc.
**OX	Coder, decoder, interrogator, transponder groups	All types.
**OY	Radar Set groups	Do not use if a more specific indicator, such as OE, OR, OT, etc., applies.
**OZ	Radio Set groups	Do not use if a more specific indicator, such as OE, OR, OT, etc., applies.
PD	Prime drivers	Gasoline engines, electric motors, synchros, diesel motors, etc.
PF	Fittings, pole	Cable hanger, clamp, protectors, etc.
*PG	Pigeon articles	Container, loft, vest, etc.
*PH	Photograghic articles	Camera, projector, sensitometer, etc.
PL	Plug-in modules	Plug-in modules not otherwise classified. Do not use if more specific indicators, such as AM, R, T, apply.
PP	Power supplies	Nonrotating machine type such as vibrator pack rectifier, thermoelectric, etc.
PT	Plotting equipments	Except meteorological. Boards, maps, transparent maps, plotting table, etc.
PU	Power equipments	Rotating power equipment except dynamotors, motor-generator, etc.
R	Receivers	Receivers, all types except telephone.
RC	Reels	All types (see RL).
RD	Recorder-reproducers	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RE	Relay assemblies	Electrical, electronic, etc.
RF	Radio frequency component	Composite component of R-F circuits. Do not use if better indicator is available.
RG	Cables, R-F, Bulk	R-F cable, waveguides, transmission lines, etc. without terminals.
RL	Reeling machines	Mechanisms for dispensing and rewinding antenna or field wire, recording wire or tape, etc.,
RO	Recorders	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RP	Reproducers	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical etc.
RR	Reflectors	Target, confusion, etc., except antenna reflectors (see AS).

Table 2-4.–Unit indicator letters–Continued.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
RT	Receiver and transmitter	Radio and radar transceivers, composite transmitter and receiver, etc.
S	Shelters	House, tent, protective shelter, etc.
SA	Switching devices	Manual, impact, motor driven, pressure operated, etc.
SB	Switchboards	Telephone, fire control, power, panel, etc.
SG	Generators, signal	Test oscillators, noise generators, etc. (see O)
SM	Simulators	Flight, aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
ST	Straps	Harness, straps, etc.
SU	Optical device	Telescopes, periscopes, projectors, and boresighting scopes.
T	Transmitters	Transmitters, all types, except telephone.
TA	Telephone apparatus	Miscellaneous telephone equipment.
TB	Towed body	Buoy, fish, paravane, target, etc.
TC	Towed cable	Articulated towing strut, faired cable, etc.
TD	Timing devices	Mechanical and electronic timing devices, range device, multiplexers, electronic gates, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning devices	Tilt and/or train assemblies.
TH	Telegraph apparatus	Miscellaneous telegraph apparatus.
TK	Tool kits	Miscellaneous tool assemblies.
TL	Tools	All types except line construction (see LC).
TN	Tuning units	Receiver, Transmitter, antenna, tuning units, etc.
TR	Transducers	Magnetic heads, phonopickups, sonar transducers, vibration pickups, etc. (see H, LS, and M).
TS	Test items	Test and measuring equipment not otherwise included; boresighting and alignment equipment.
TT	Teletypewriter and facsimile apparatus	Miscellaneous tape, teletype, facsimile equipment, etc.
TV	Tester, tube	Electronic tube tester.
TW	Tapes and recording wires	Recording tape and wire, splicing, electrical insulating tape, etc.
U	Connectors, audio and power	Unions, plugs, sockets, adapters, etc.
UG	Connectors, R-F	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
V	Vehicles	Carts, dollies, trucks, trailers, etc.
VS	Signaling equipment, visual	Flag sets, serial panels, signal lamp equipment, etc.
WD	Cables, two-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WF	Cables, four-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WM	Cables, multiple-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WS	Cables, single-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WT	Cables, three-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
ZM	Impedance measuring devices	Used for measuring Q, C, L, R, or PF, etc.

*NOTE: Inactivated for U S. use except for assigning modifcation letters to previously type-designated items

**NOTE: Collection of items part of or used with one set or set series.

the equipment. Each performance procedure in this section includes instructions essential for the proper use of the test equipment in diagnosing a trouble within a specific equipment.

Section VII, Diagrams, is described later in this chapter, under the heading, "Drawings, Schematics, and Charts."

Section VIII, Difference Data Sheets, may be added (when required) to provide information on improved or modified models of the original equipment.

Overhaul Instruction Manual

The Overhaul Instruction Manual provides detailed information for overhauling the electronics equipment and/or component. This includes such procedures as disassembly, cleaning, repair, recalibration, testing, and any other steps necessary for complete overhaul. The manual also includes a tabulated list of test equipment recommended for overhaul. It is issued primarily to overhaul activities because the nature of the work described is usually beyond the capacities and facilities of field maintenance activities.

Illustrated Parts Breakdown

The Illustrated Parts Breakdown for equipments is similar in format, purpose, and usage to the IPB for aircraft as previously discussed.

Combined Manuals

Frequently, especially for components and small items of electronics test equipment, two or more of the above manuals are combined into a single publication. In most of these cases, the general material content may be determined from the title, but the arrangement of sections within the manual will vary with the individual publication.

REVISIONS

In an effort to provide maintenance activities with the latest and most accurate information possible, the Naval Air Systems Command has instituted a program of continuous review and frequent revision of technical publications and manuals. These revisions are classed as formal or informal.

FORMAL revisions are printed and distributed as a new manual or as a partial replacement on a page-by-page basis. Formal revisions are reflected in the cumulative supplement to NavSup publication 2002. INFORMAL revisions include changes authorized by other means such as messages, notices, letters, or periodicals. They are normally "pen-and-ink" type changes.

Incorporation of Revised Material

When making a pen-and-ink change to any official publication or directive, be sure to record the source of the corrected material or the authority for the change. In this manner, subsequent users of the document will know that the change is official and also where to look for additional details. Eliminating the confusion which results from too much information, some of which may be incorrect, will make the document much more valuable as a tool for maintenance.

When making a substitute page type revision to a manual, be sure to double check that all instructions forwarded with the change copy are complied with. These instructions normally include the removal of certain pages, and substitution of other pages in their place. Be sure that all canceled pages are removed and disposed of in the proper manner, and that all pages not canceled are retained in their proper sequence.

When making a revision of any type to any official document, record the data concerning the number of the change, authority, date of the incorporation of the revision, and the name or initials of the person making the incorporation. In most technical manuals, a special page is included for this purpose.

Reporting of Errors in Manuals

As a part of the program to improve the quality and accuracy of its technical manuals, the Naval Air Systems Command has initiated a program for encouraging users to report errors and discrepancies. At the time of this writing, the program applies only to certain specified types of manuals; however, it is expected that the program will be expanded in the near future to include all technical manuals. The basic reporting document is the Unsatisfactory Material/Condition Report (UR), OpNav 4790/47.

SPECIFICATIONS

A specification is a minutely detailed description or designation of the characteristics, particulars, values, or tolerances which must be met by a product or process.

The technician is concerned with specifications every time he performs an inspection, calibration, adjustment, operation, or repair on any unit of electronic equipment. In order for the equipment to fulfill its purpose, it must operate in a specified manner–it must meet definite requirements of sensitivity, power output, timing, phase, frequency, signal characteristics, etc. Specifications for a particular unit are found in the operation and inspection manuals and procedures for the applicable aircraft or equipment.

Failure of an item of electronics equipment to meet its specifications will prevent the aircraft from performing at its maximum capability. This condition calls for the removal, adjustment, repair, or calibration of the defective unit. To insure that all equipments are operating within the tolerances allowed in the specifications, operational inspections must be performed at frequent intervals, and in a precise and thorough manner.

Federal Specifications

Federal specifications are prepared under the direction of and promulgated by the Administrator of General Services, and apply to items in general usage by governmental agencies.

Military Specifications

Military specifications cover materials, products, or services used predominantly by military activities, but which may be used by other federal agencies. These specifications are issued and promulgated by the Office of Standardization, Defense Supply Agencies.

Standards

A standard is a reference or a sample set up or established by competent authority to be used as a guide for comparison or evaluation.

The technician is constantly involved with standards. Every time he measures voltages in a circuit, he is comparing the potentials in that particular circuit with the standard volt. Every time he reads a schematic or block diagram, he recognizes the standard symbols used in the drawing. Every time he reads an explanation of the theory of operation for a circuit, he recognizes and understands the meaning of standard terms. When he replaces a defective resistor or capacitor, he installs a standard item.

Standards make possible the rapid, clear, and concise communication of facts, ideas, and information; without standards, modern technology would be impossible.

FEDERAL STANDARDS.–Federal standards are documents that establish engineering and technical limitations for items, materials, processes, methods, designs, and engineering practices. These documents are for general use by governmental agencies.

MILITARY STANDARDS.–Military standards are documents that establish engineering and technical limitations and applications for items, materials, processes, methods, designs, and engineering practices. These documents are intended primarily for use by agencies of the Department of Defense.

INSTRUCTIONS AND NOTICES

The Navy Directives System is used throughout the Navy for the issuance of directive type releases. Some of these prescribe policy, organization and methods, or procedures; others contain general information. The directives system provides a uniform plan for issuing and maintaining directives; conformance is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan–Instructions and Notices.

Information pertaining to action of a continuing nature is contained in Instructions. An

Instruction has permanent reference value and remains in effect until the originator supersedes or cancels it. Notices contain information pertaining to action of a onetime nature. A Notice does not have permanent reference value and contains provisions for its own cancellation.

For purposes of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation; the type of release (whether an Instruction or Notice); a subject classification number; and, in the case of Instructions only, a consecutive number. (Because of their temporary nature, the consecutive number is not assigned to Notices.) This information is assigned by the originator and is placed on each page of the release.

The manner of numbering and identifying directives can be better understood by considering a typical identifier:

SECNAV	INST	5215.	1A
(a)	(b)	(c)	(d)

(a) The authorized abbreviation of the originator of the directive.

(b) The type of release (in this case an Instruction).

(c) The subject number of the directive (obtained from the Table of Subject Classification Numbers).

(d) The consecutive number (found only on Instructions). An originator would assign consecutive numbers to those consecutive instructions with the same subject classification number. In the example above, the subject classification number 5215 concerns "Issuance Systems." If the originator, SecNav, issued additional Instructions dealing with issuance systems, they would be assigned the numbers 5215.2, 5215.3, 5215.4, etc. The letter A indicates that this is the first reissue of the same basic directive.

Subject classification numbers are listed in the Table of Subject Classification Numbers found in SecNav Instruction P5210.11. This table contains a numerical and alphabetical listing of numbers with their related subjects, and has reference value when information or instructions of a particular nature are desired. This Instruction contains all necessary information concerning the use and procedures of the Navy Directives System.

TECHNICAL DIRECTIVE SYSTEM

The Technical Directive (TD) System has been established for control and issue of all technical directives. This system standardizes the method of issuance for such directives and is the authorized means for directing the accomplishment and recording of modifications and onetime inspections to equipment procured by and for the NavAirSysCom. The TD system is an important element in the programs designed to maintain equipment in a configuration which provides the optimum conditions of safety and operational and material readiness. This system encompasses two types of Technical Directives differentiated by their method of dissemination. These two types are Formal (letter type) and Interim (message type). In general terms, they are both considered as letter type technical directives. These directives contain instructions or information of a technical nature which cannot be satisfactorily disseminated by revisions or changes to technical manuals. This information (instructions) is disseminated in the form of Changes, or in the case of special circumstances, by Interim Changes or Bulletins.

A formal TD is a document issued as a Change, or an Amendment or Revision thereto, and promulgated by letter. Formal technical directives are used to direct the accomplishment and recording of modifications to weapons, weapons systems, support equipment, trainers, and related equipment and are comprised of changes and amendments and/or revisions thereto.

An interim TD is a document issued as a Bulletin or a Change, or as an Amendment or Revision thereto, and promulgated by message to insure expeditious dissemination. The interim TD is reserved for those instances requiring expeditious correction of an operational or safety condition which embodies risks calculated to be intolerable within the lead time of a formal directive or maintenance publication change. Interim Changes are superseded by a formal change directive which will have the same number as the interim directive. Interim Bulletin directives are not superseded by formal bulletins as was previously the case. The NavSup 2002, Section VIII, Part D, will still have many formal bulletins listed until they are eventually phased out.

A Change is a document containing instructions and information which directs the accomplishment and recording of a material change, a repositioning, a modification, or an alteration in the characteristics of the equipment to which it applies. A Change is issued to direct that parts be added, removed, or changed from the existing configuration or that parts or material be altered, relocated, or repositioned.

A Change may be issued in parts to accomplish specific parts of a total directed action or to accomplish action on different configurations of affected equipment. A Change may also be issued for Record Purposes. A Record Purpose Change is a TD issued to provide documentation of a modification which has been completely incorporated by the contractor or in-house activity in all accepted equipment and which does not require retrofit or the modification of repairables in the Navy's possession.

An Amendment is a document comprised of information which clarifies, corrects, adds to, deletes from, makes minor changes in requirements to, or cancels an existing technical directive. It is only a supplement to the existing directive and not a complete directive in itself. A maximum of three Amendments may be applied to a TD, each remaining in effect until rescinded or superseded by a Revision. A requirement for further amendment action necessitates the issuance of a Revision.

A Revision is a completely new edition of an existing directive. It supersedes the original directive or revision and all existing amendments.

A Bulletin is an interim document comprised of instructions and information which directs an initial inspection to determine whether a given condition exists. It specifies what action is to be taken if a given condition is found or not found.

Interim bulletin directives are self-rescinding with rescission dates of 30 June or 31 December, whichever is appropriate for the case at hand. Rescission is the process by which TD's are removed from active files after all requirements have been incorporated. Final rescission action is directed in the TD Index, NavSup Publication 2002, Section VIII, Part D. All activities maintaining active technical libraries should maintain the TD's on file until they are deleted from the TD Index.

Cancellation of a technical directive is the process whereby the TD is removed from the active files when it is determined that a previously issued TD is not to be incorporated. Cancellation is directed by the issuance of an Amendment to the TD. The cancellation explicitly states the required configuration of each article initially specified for modification; for example, whether installed modifications are to remain installed or are to be removed, etc.

The title subject of a Change or Bulletin will be one of the following as appropriate:

Airframe
Powerplant
Avionics
Aviation Armament
Support Equipment
Propeller
Photographic
Airborne Weapon
Aircrew System
Accessory
Target Control System
Meteorological Equipment

EXAMPLES:

Avionics Change No. 85A
J-79 Powerplant Change No. 27
Air Crew System Change No. 289
A-4 Interim Airframe Change No. 261
A-5 Interim Airframe Bulletin No. 111

If the technical directive involves safety of flight the word "SAFETY" will appear immediately following the title and number.

Technical directives are numbered by two different methods. Some are numbered consecutively from the beginning of the calendar year with the last two digits indicating the year of issue. Thus, a Change or Bulletin designated 47-54 would be the 47th Change or Bulletin of that type issued in 1954. This type of numbering system is no longer being used for identifying new directives. However, those which have been numbered in this manner and are still in effect are cataloged under this system.

The present numbering system is a consecutive numerical application regardless of the year of issue. For example, Avionics Change 204 would be the 204th Avionics Change issued. This numbering system has been in effect for some time and most technical directives are cataloged under this system.

The numbers assigned to Changes and Bulletins are provided by the Technical Directives Control Center, which is located at the Naval Air Technical Services Facility (NATSF), Philadelphia. Changes or Bulletins that have been amended will have their basic number followed by the words "Amendment 1," "Amendment 2," etc. A revised directive will have the basic directive number followed with the words "Rev. A," "Rev. B," etc., as appropriate to denote the first, second, etc., revision to that basic directive.

The Changes and Bulletins are automatically distributed to all concerned activities. All TD's are issued by NavAir or NavAirTechSerFac except in cases where the time delay in obtaining approval is unacceptable. In such cases the controlling custodians are authorized to issue interim TD's to preclude unacceptable risks to personnel or equipment. The Changes or Bulletins are generally based on Contractor Service Bulletins, other letters of recommendation, or proposed modifications from field service activities.

Directive Categories

Technical directives are assigned a "category" in accordance with the importance and urgency of accomplishing the work involved. A category of Immediate, Urgent, Routine, or Record Purpose is assigned each technical directive.

The category Immediate Action is assigned to directives which are issued to correct safety conditions, the uncorrected existence of which would probably result in fatal or serious injury to personnel, extensive damage, or destruction of property. These directives are identified by a border of red X's broken at the top center of the page by the words IMMEDIATE ACTION.

The category Urgent Action is assigned to directives which are used to correct safety conditions which, if uncorrected, could result in personnel injury or property damage. These directives are identified by the words URGENT ACTION at the top of the first page and a border of red diagonals around the cover page.

Routine Action directives are those concerned with equipment or procedural deficiencies of a material—mechanical, operational, or tactical in nature—the uncorrected existence of which could constitute a hazard. They are identified by the words ROUTINE ACTION printed at the top of the cover page.

The category Record Purpose is used when a modification has been completely incorporated by the contractor or in-house activity in all accepted equipment and when retrofit is not required of repairables in the Navy's possession. They are identified by the words RECORD PURPOSE printed in black capital letters at the top center of the first page.

PERIODICALS

Many periodicals of interest to the technician are published and issued by naval activities and commands. A few of the most important are discussed in the following paragraphs.

Approach

Approach, The Naval Aviation Safety Review, is published monthly by the U.S. Naval Aviation Safety Center. It is distributed to naval aeronautical organizations on the basis of one copy for each ten personnel assigned. It presents the most accurate information currently available on the subject of aviation accident prevention. It is an unofficial publication, and its contents are not to be considered as regulations, orders, or directives. It should, however, be read each month by all aviation personnel.

Naval Aviation News

Naval Aviation News is published monthly by the Chief of Naval Operations and the Naval Air Systems Command. Its purpose is to disseminate information on aircraft, aviation training and operations, and other aeronautical matters. This publication should be read each month by all naval aviation personnel.

Naval Ordnance BULLETIN

The Naval Ordnance BULLETIN is a magazine issued quarterly by the Naval Ordnance

Systems Command. This Bulletin contains information concerning aviation and ordnance projects of special and general interest, including new developments. The information ranges from suggestions which should help in using present equipment to furnishing a background of information on advanced developments and concepts. (This publication is normally classified CONFIDENTIAL.)

Mech

Mech, the Naval Aviation Maintenance Safety Review, is published quarterly and is directed at the enlisted aviation maintenance personnel. It presents the most accurate information available on maintenance-caused mishap prevention and general aviation ground safety directed at reducing maintenance errors and handling mishaps. Contents of Mech are intended to be informational and should not be considered as orders, regulations, or directives.

All Hands

ALL HANDS, Nav-Pers-0 Series, the Bureau of Naval Personnel Career Publication, is published monthly by the Bureau of Naval Personnel for the information and interest of the naval service as a whole. It is not an official publication in the sense of constituting authority for action based on information contained therein; nor is it a statement of official policy. However, it is an important publication in that it contains information vital to naval personnel.

Distribution of All Hands is automatic to each activity, and is based on one copy for each ten personnel assigned. It should be read every month by all personnel.

DRAWINGS, SCHEMATICS, AND CHARTS

Nearly all technical manuals make extensive use of drawings and diagrams. The technician uses these drawings and diagrams in locating and identifying units and components, troubleshooting, signal and/or circuit tracing, and installing and adjusting replacement units. They are also useful in studying the principles of operation of circuits and equipments.

No one particular type illustration is suitable for all applications; therefore, many different types are required. Several of the different types are discussed in the following paragraphs. Each type has its own advantages and disadvantages.

ILLUSTRATIONS

Illustrations are commonly used to present visually the idea of a text. To this end, illustrations are used in many forms. A few of these are the photograph, line drawing, shaded sketch, cutaway view, blueprint, etc. Some of the more common illustrations are discussed briefly in this chapter.

Pictorial

Pictorial illustrations normally indicate physical appearance. They may present details concerning the location, size, construction, physical relationships of size and location, or parts arrangement. They appear throughout manuals of all types, and are useful for locating and identifying systems, equipments, components, or parts. They are used in connection with installation, inspection, servicing, operation, adjustment, calibration, troubleshooting, and repair functions.

Pictorial illustrations may be accurately detailed representations, or they may be merely generalized indications, depending on their purpose. They may be photographs, halftone or shaded sketches, or line drawings.

Cutaway View

A cutaway view is an illustration used to show some detail of construction which would be extremely difficult or impossible to show by conventional pictorial views. It is often used in connection with discussions of physical construction and the operation of mechanical devices. It is frequently used in assembly diagrams and in construction details.

Location and Dimension

Location diagrams are used to show physical position relationships, and may or may not be sufficiently detailed to show physical appearance. They are primarily useful for familiarization, and are commonly used in Flight Manuals, in the General Information and Servicing section of the Maintenance Instructions Manuals (MIM's), in the Illustrated Parts Breakdown Manual (IPB), and in the Operation and Maintenance Instructions for equipments.

Dimension diagrams denote physical size and distance. They are useful in planning the layout of bench stations, making equipment installations, or packing materials for reshipment. They are frequently used in the general information sections of technical manuals, and in those sections devoted to familiarization, installation and shipment. They are also frequently found in change type technical directives.

Location and/or dimension diagrams may be combined with other type illustrations, thus providing additional details without increasing the number of illustrations.

Assembly Diagrams

Assembly diagrams, as the name implies, provide details of construction which are useful in assembling parts into a unit. They are also useful in explaining the operation of mechanical or electromechanical devices.

BLOCK DIAGRAMS

Block diagrams are not used to show physical shape, size, or location; they are used to present a generalized explanation of overall functional operation. They range from very simple to very complex, depending on the type equipment, the quantity and quality of details to be covered, and the purpose for which the information is included. They are found in nearly all manuals dealing with basic or detailed theory of operation, whether of relatively simple subassemblies or of very large and complex systems. The more complex the equipment, the more probable the need for block diagrams.

Many block diagrams are used in connection with electromechanical devices, as well as with electrical or mechanical systems. Proper use of this type diagram helps increase understanding of functional relationships and operation.

Symbols

Since block diagrams are used mainly to provide a general analysis of functional operation, symbols are generally used to represent individual circuits or functional components. In order to make maximum use of block diagrams, it is essential to recognize the symbols, and to understand their meanings and limitations. Appendix II of this manual contains many of the common symbols found on block diagrams. Numerous block diagrams are included in this manual.

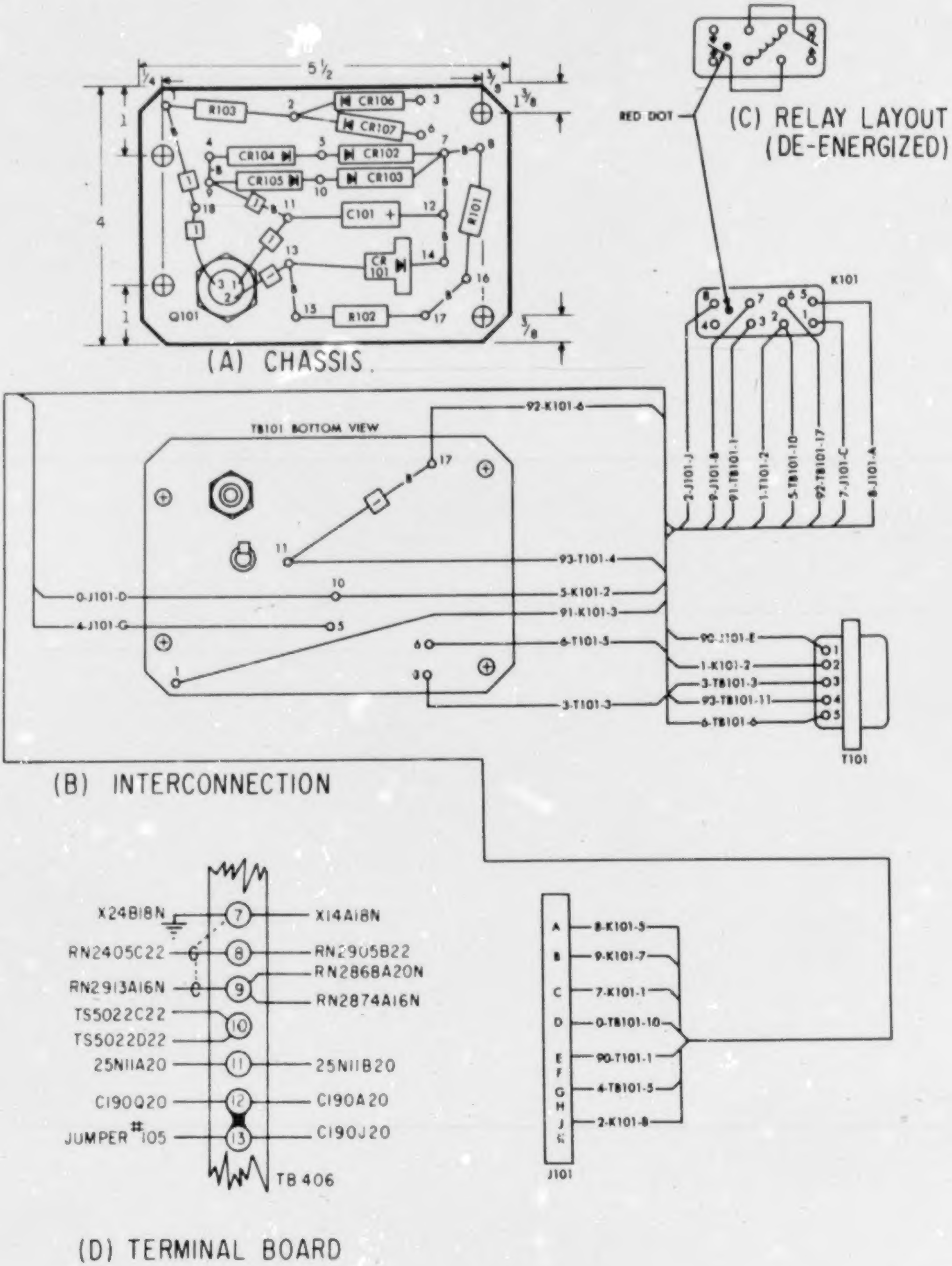
Signal Flow

One special type of block diagram is called the signal flow diagram or signal flow chart. It is usually used in connection with overall operation of complicated systems such as fire control computers, ASW systems, aircraft control or power distribution systems, or search or navigation radar systems. It includes all features normally associated with block diagrams, and in addition it includes considerable detail regarding signal paths, signal wave-shape, timing sequence and relationships, magnitudes of potentials or signals, frequencies, etc.

WIRING DIAGRAMS

The wiring diagram presents detailed circuitry information concerning electrical and electronics systems. A master wiring diagram is a single diagram that shows all the wiring in a complete system or in an aircraft. In most cases, this diagram would prove to be too large to be usable; it is normally broken down into logical functional sections, each of which may be further subdivided into circuit diagrams. By breaking a system into individual circuit diagrams, each individual circuit may be presented in greater detail. The increased detail provides for easier circuit tracing, testing, and maintenance.

Wiring diagrams fall into two basic classes—chassis wiring and interconnecting diagrams—each with specific purposes and many variations in appearance (depending on application). Wir-


(A) CHASSIS
5 1/2
1/4
3/8
1 3/8
1
4
1
5/8
R103
CR106
CR107
CR104
CR102
CR105
CR103
C101
R101
CR 101
R102
Q101
(B) INTERCONNECTION
TB101 BOTTOM VIEW
92-K101-6
93-T101-4
0-J101-D
5-K101-2
91-K101-3
4-J101-G
6-T101-5
3-T101-3
90-J101-E
1-K101-2
3-TB101-3
93-TB101-11
6-TB101-6
T101
2-J101-J
9-J101-B
91-TB101-1
1-T101-2
5-TB101-10
92-TB101-17
7-J101-C
8-J101-A
RED DOT
(C) RELAY LAYOUT
(DE-ENERGIZED)
K101
8-K101-5
9-K101-7
7-K101-1
0-TB101-10
90-T101-1
4-TB101-5
2-K101-8
J101
X24B18N
X14A18N
RN2405C22
RN2905B22
RN2868A20N
RN2913A16N
RN2874A16N
TS5022C22
TS5022D22
25N11A20
25N11B20
C190Q20
C190A20
JUMPER #105
C190J20
TB 406
(D) TERMINAL BOARD

AT.18

Figure 2-3.–Wiring diagrams. (A) Chassis wiring; (B) interconnection wiring; (C) sealed component parts layout; (D) terminal board connections.

ing diagrams are not generally used for discussions of theory of operation of specific circuits.

Figure 2-3 (A) is an example of one type chassis wiring diagram commonly used. This drawing shows the physical layout of the unit, and all component parts and interconnecting tie points are shown. Each indicated part is identified by reference designation number, thus facilitating use of the IPB to determine values and other data. (The values of resistors, capacitors, or other components are normally not indicated on wiring diagrams.) The polarity of semiconductor diodes and of the polarized capacitor is shown. Since this specific diagram shows physical layout and dimensioning details for mounting holes, it could be used as an assembly drawing and also as an installation drawing.

Figure 2-3 (B) shows the reverse side of the same mounting board, together with the wiring interconnections to other components. Actual positioning of circuit components is not indicated, and wire bundles are represented as single lines with the separate wires entering at an angle. (The angle indicates the direction to follow in tracing the circuit to locate the other end of the wire.)

The wire identification coding on this diagram consists of a three-part designation. The first part is a number representing the color code of the wire in accordance with Military Specification MIL-W-76A. (Many other chassis wiring diagrams designate color coding by abbreviations of the actual colors.) The second is the reference part designation number of the item to which the wire is connected. The last is the designation of the specific terminal to which connection is made.

Figure 2-3 (C), while not a wiring diagram, illustrates a method commonly used to show some functional aspect of sealed or special components.

Figure 2-3 (D) illustrates several methods used to indicate connections at terminal strips. The details of wire identification coding used are discussed below.

Wiring diagrams are normally the major content of the last volume of a MIM set, or the last section of most other maintenance manuals. This volume or section contains wiring diagrams for all electrical and electronic systems of the aircraft. The diagrams are prepared separately for each circuit and provide all data necessary to understand the construction of each circuit, to trace each circuit within the system to make continuity and resistance checks, and to perform specific troubleshooting on inoperative or malfunctioning circuits.

Aircraft Wire Identification Coding

To facilitate maintenance, all aircraft wiring is identified on the wiring diagrams exactly as marked in the aircraft. Identification of each wire is coded by a combination of letters and numbers imprinted on the wire at prescribed intervals along its entire run. Figure 2-4 and the accompanying discussion explain the code used in aircraft wiring installation. Complete details are to be found in the latest revision of MIL-W-5088.

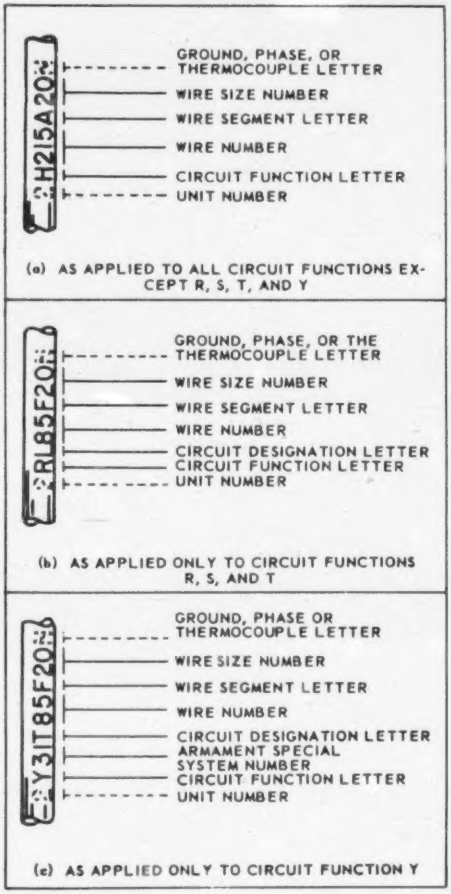
The unit number (shown in dashed outline) is used only in those cases having more than one given unit installed in an identical manner in the same aircraft. The wiring concerned with the first such unit bears the prefix 1, and corresponding wires for the second unit have exactly the same designation except for the prefix 2, etc.

The circuit function letter identifies the basic function of the unit in accordance with table 2-5. Note that circuit function R, S, and T wiring may bear a second letter to designate the functional breakdown of the circuit.

Each wire within a given circuit function group is assigned a separate wire number. Wires that are segmented by the use of splices, plug and receptacle connectors, terminal strip tie points, etc., are given a letter segment designation. Passage through a switch, relay, circuit breaker, etc., requires assignment of a new number.

Wire size numbers are omitted in the case of coaxial cables; they are replaced by a dash and coded designator when part of a thermocouple arrangement.

A suffix is added to designate the phase (or ground) in 3-phase a-c power wiring. In the case of thermocouples the suffix denotes the metal element involved.


H215A20
GROUND, PHASE, OR THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT FUNCTION LETTER
UNIT NUMBER
(a) AS APPLIED TO ALL CIRCUIT FUNCTIONS EXCEPT R, S, T, AND Y
RL85F20
GROUND, PHASE, OR THE THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT DESIGNATION LETTER
CIRCUIT FUNCTION LETTER
UNIT NUMBER
(b) AS APPLIED ONLY TO CIRCUIT FUNCTIONS R, S, AND T
Y31T85F20
GROUND, PHASE OR THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT DESIGNATION LETTER
ARMAMENT SPECIAL SYSTEM NUMBER
CIRCUIT FUNCTION LETTER
UNIT NUMBER
(c) AS APPLIED ONLY TO CIRCUIT FUNCTION Y

AT. 19

Figure 2-4.—Example of wire identification coding.

Cable Construction

Cable construction diagrams present details concerning the fabrication and construction of cables. These details usually include designation of the type connectors or terminals, the identification of wires for each terminal, method of connecting wire to terminal, potting requirements, length of wires, lacing or sleeving specifications, and any other specifications, or special considerations involved.

Cable Routing

Diagrams of major systems generally include an isometric shadow outline of the aircraft showing the approximate location of equipment components, and the physical routing of interconnecting cables. A cable, regardless of the number of conductors, is represented on an isometric wiring diagram as a single line; no attempt is made to show individual connections at equipment units or in connection boxes. An isometric type drawing thus shows at a glance a picture of the layout of the entire system.

SCHEMATICS

The major purpose of the schematic diagram is to establish the electrical operation of a particular system. It is not drawn to scale, and it shows none of the actual construction details of the system (such as a physical location within the aircraft, physical layout of components, wire routing, or any other physical detail) not essential to understanding circuit operation.

Schematic drawings differ from block diagrams (discussed earlier) by presenting more detail concerning each circuit. Whereas the block diagram deals with functional units of the system, the schematic diagram indicates each individual part which contributes to the functional operation of the circuit.

NOTE: The National Bureau of Standards is now using in all its publications the term hertz, abbreviated Hz, as the term applied to a unit of frequency, one hertz being one cycle per second. Table 2-6 will give you a quick rundown of a few applications of the term to show you how it works.

Simplified Schematics

In large or complex equipments, a complete schematic drawing may be too large for practical use. For this reason, most technical manuals present partial or simplified schematics for individual circuits or units.

Table 2-5.—Wiring circuit function code.

Circuit function letter	Circuits
A	Armament
B	Photographic
C	Control surface
D	Instrument
E	Engine instrument
F	Flight instrument
G	Landing gear
H	Heating, ventilating, and de-icing
J	Ignition
K	Engine control
L	Lighting
M	Miscellaneous
P	D-c power
	Wiring in the d-c power or power control system will be identified by the circuit function letter P.
Q	Fuel and oil
R	Radio (navigation and communication)
	RN-Navigation
	RP-Intercommunications
	RZ-Interphone, headphone
S	Radar
	SA-Altimeter
	SN-Navigation
	SQ-Track
	SR-Recorder
	SS-Search
T	Special electronic
	TE - Countermeasures
	TN-Navigation
	TR-Receivers
	TX-Television transmitters
	TZ-Computer
V	D-c power and d-c control wires for a-c systems will be identified by the circuit function letter V.
W	Warning and emergency
X	A-c power
	Wiring in the a-c power system will be identified by the circuit function letter X.
Y	Armament special systems

Table 2-6.—Hertz table.

Unit/quantity	Old term	Old abbrev.	New term	New abbrev.
Frequency	Cycles Per Second	cps	hertz	Hz
10^{-3} Cycles Per Second	Millicycles Per Second	mc	Millihertz	mHz
10^{3} Cycles Per Second	Kilocycles Per Second	kc	Kilohertz	kHz
10^{6} Cycles Per Second	Megacycles Per Second	Mc	Megahertz	MHz
10^{9} Cycles Per Second	Gigacycles Per Second	Gc	Gigahertz	GHz

Simplified schematics normally omit parts and connections which are not essential to understanding circuit operation. In studying or troubleshooting equipment, the technician frequently must make his own simplified drawings. In these cases he should include only those items that contribute to the purpose of the drawing, but he should take care to include all such items. In using the schematic drawings throughout this manual (and those in technical manuals, textbooks, and other publications), many techniques for simplifying schematics will become apparent. Special attention should be paid to those techniques found useful by the individual maintenance man—they can be extremely important tools in his work.

Electromechanical Drawings

Electromechanical devices such as synchros, gyros, accelerometers, autotune systems, analog computing elements, etc., are quite common in avionics systems. For a complete understanding of these units, neither an electrical drawing nor a mechanical drawing would be adequate—and confusion could result from the use of two drawings. Therefore a combination type drawing, using some aspects of each component type, is used. These drawings are usually simplified both electrically and mechanically, and only those items essential to the operation are indicated on the drawing.

CHARTS AND TABLES

Charts and tables of many types are used throughout all types of technical publications to present factual data in a clear and concise form. As the terms are used in this discussion, a chart is used to present information in lists, pictures, tables, or diagrams; a table is one type of chart, and is used to present or list information in a very condensed form.

Tables prove valuable in instances when the same general type information is to be presented with respect to numerous items. The corresponding details for the items may be listed in columns, arranged so that reading across will present details regarding a specific item, while reading down will present a comparison of items with respect to a certain detail. One very common and useful table of this type is represented by the IPB listings discussed earlier in this chapter.

CHAPTER 3

ELEMENTARY PHYSICS

The Navy technician is associated with some very complex machines and equipment. He is expected to understand, operate, service, and maintain these machines and equipment, and to instruct new men so that they can also perform these functions. No matter how complex a machine or item of equipment is, its action can be satisfactorily explained as an application of a few basic principles of physics. In order to understand, maintain, and repair the equipment and machinery necessary to the operation of the ships and aircraft of the fleet, an understanding of these basic principles is essential. There can be no question that the technician who possesses this understanding is better equipped to meet the demands placed upon him in his everyday tasks.

Physics is devoted to finding and defining problems, as well as to searching for their solutions. It not only teaches a person to be curious about the physical world, but also provides a means of satisfying that curiosity. The distinction between physics and other sciences cannot be well defined, because the principles of physics also pertain to the other sciences. Physics is a basic branch of science and deals with matter, motion, force, and energy. It deals with the phenomena which arise because matter moves, exerts force, and possesses energy. It is the foundation for the laws governing these phenomena, as expressed in the study of mechanics, hydraulics, magnetism, electricity, heat, light, sound, and nuclear physics. It is closely associated with chemistry and depends heavily upon mathematics for many of its theories and explanations.

BASIC CONCEPTS

In any study of physics, it soon becomes obvious that specific words and terms have specific meanings which must be mastered from the very start. Without an understanding of the exact meaning of the term, there can be no real understanding of the principles involved in the use of that term. Once the term is correctly understood, however, many principles may be discussed briefly to illustrate or to emphasize the particular aspects of interest. The first part of this chapter is devoted to definitions of some physical terms and a brief general discussion of certain particular principles of vital interest to all technical personnel.

MEASUREMENT

In all branches of science, measurement is a very important consideration. In order to evaluate results, it is often essential to know how much, how far, how many, how often, or in what direction. As scientific investigations become more complex, measurements must become more accurate, and new methods must be developed to measure new things.

Measurements may be classed in three broad categories—magnitude, direction, and time. These categories are broken down into several types, each with its own standard units. Measurements of direction and time have become fairly well standardized and have comparatively few subdivisions. Magnitude, on the other hand, is an extremely complex category with many classes and subdivisions involved.

The unit of measurement is just as important as the number which precedes it, and both are necessary to give accurate description.

Two widely used sets of fundamental units are the metric and the English. The metric units are most often used to express scientific observations where the basic unit of distance is the meter, of mass is the kilogram, and of time is the second. This is called the meter-kilogram-second system, or the mks system. Another widely used metric system uses the centimeter for units of distance, the gram for units of mass, and the second for units of time, and so is called the centimeter-gram-second system, or cgs system. The English system uses the foot for distance, the pound avoirdupois for mass, and the second for time, and so is called the foot-pound-second system, or fps system. See table 3-1 for other units.

Units of Distance Measurement

The AT should be familiar with both the English and the metric systems of measurement. For example, radar range units are usually expressed in the English system as yards or miles, while wavelength is most often expressed in the metric system with the meter as the basic unit.

Table 3-1.—Frequently used units of measurement.

English system
- acre
- Btu (British thermal unit)
- bushel
- dram
- foot
- gallon
- hertz
- horsepower
- hour
- inch
- knot
- mil
- mile
- minute
- ounce
- peck
- pint
- pound
- quart
- second
- slug
- ton (short, 2,000 lb long, 2,240 lb)
- yard

Metric system
- angstrom
- bar
- calorie
- dyne
- erg
- gram
- hectare
- hertz
- hour
- joule
- liter
- meter
- metric ton (1,000 kg)
- micron
- minute
- newton
- quintal
- second
- stere

General
- ELECTRICAL
  - ampere
  - coulomb
  - decibel
  - farad
  - henry
  - ohm
  - volt
  - watt
- LIGHT
  - candle
  - candela
  - lambert
  - lumen
- MAGNETIC
  - gauss
  - gilbert
  - maxwell
  - rel

METRIC UNITS OF LENGTH.—Metric units of length are based on the standard meter which was first intended to be one ten-millionth part of the distance between the earth's Equator and one of the poles. Although more recent measurements show this distance to be close to 10,000,880 meters, the original length of the meter is still accepted as standard.

When large distances are measured it is customary to use the kilometer, which is 1,000 meters; 1 kilometer (km) = 1,000 meters (m). For smaller measurements the meter is divided into smaller units. One meter equals 100 centimeters (1 m = 100 cm) and 1 centimeter equals 10 millimeters (1 cm = 10 mm), so 1 meter equals 1,000 millimeters (1 m = 1,000 mm). The table in Appendix III lists other prefixes used with basic units.

The micron is still smaller, and is the unit often encountered in stating, the wavelength of light, or in referring to the size of a particle of foreign matter that may pass through a certain screen or filter in the liquid cooling system of electronic equipment. The micron is one-thousandth of a millimeter or one-millionth of a meter, the millimicron is one-thousandth of a micron, and the micromicron is one-thousandth of a millimicron or one-millionth of a micron.

ENGLISH UNITS OF LENGTH.—The common units of the English system of distance measurement are inches, feet, yards, and miles, where 1 foot equals 12 inches (1 ft = 12 in.), 1 yard equals 3 feet (1 yd = 3 ft = 36 in.) and 1 mile equals 1,760 yards (1 mile = 1,760 yd = 5,280 ft = 63,360 in.). The nautical mile is 6,076.115 feet. The mil is 1/1000 inch.

In 1866 the United States, by an act of Congress, defined the yard to be 3600/3937 part of a standard meter, or in decimal form approximately 0.9144 meter. Thus, other comversions between the systems may be found by proper multiplication or division. Some approximate conversions are listed in table 3-2.

Table 3-2.–Conversion factors for units of length.

	km	m	cm	mm	in.	ft	yd	mile
1 km =	1	1,000	100,000	$1 \times 10^{+6}$	39,370	3,280.83	1,093.61	0.621369
1 m =	0.001	1	100	1,000	39.37	3.28083	1.09361	6.214×10^{-4}
1 cm =	1×10^{-5}	0.01	1	10	0.3937	0.032808	1.094×10^{-2}	6.214×10^{-6}
1 mm =	1×10^{-6}	1×10^{-3}	0.1	1	0.03937	3.28×10^{-3}	1.094×10^{-3}	6.214×10^{-7}
1 in. =	2.54×10^{-5}	2.54×10^{-2}	2.54	25.4	1	0.08333	0.02777	1.58×10^{-5}
1 ft =	3.048×10^{-4}	0.3048	30.48	304.8	12	1	0.33333	1.89×10^{-4}
1 yd =	9.144×10^{-4}	0.9144	91.44	914.4	36	3	1	5.68×10^{-4}
1 mile =	1.60934	1,609.34	160,934	1,609,340	63,360	5,280	1,760	1

NOTE: When a number is multiplied by a power of ten, the decimal point is moved the number of places represented by the power. A negative power moves the decimal point to the left; a positive power moves it to the right. Thus, $84 \times 10^{-2} = .84$, and $84 \times 10^{2} = 8,400$. Simply stated, a power of ten merely moves the decimal point left or right.

Units of Mass, Weight, and Force

The measure of the quantity of matter which a body contains is called mass. The mass of a body does not change. It may be compressed to a smaller volume, or expanded by the application of heat, but the quantity of matter remains the same.

It was intended that the metric unit of mass be based on the gram (gm) being equal to the mass of 1 cubic centimeter of pure water at a temperature of 4° Celsius, and for practical purposes this is essentially correct. The U.S. Bureau of Standards has two blocks of platinum which are identical to the standard kilogram (1,000 gm) block of platinum preserved at the International Bureau of Weights and Measures near Paris. The standard pound (lb) is the mass equal to 0.4536 kilograms or, 453.6 grams.

The mass of a body is constant no matter where the body is located. Its weight, however, is the force with which it is attracted toward the earth, and is slightly higher at the poles than at the Equator, and becomes less as the body is moved away from the earth's surface.

In addition to grams, kilograms, and pounds being used as units of mass, these same units are also used to describe the weight of a body by comparing the body's weight to the weight of a standard mass unit. Unless otherwise specified, when an object is described as having a weight of 1 pound, it means the object has the same pull of gravity that a mass of 1 pound would have near the earth's sea level. At sea level, the numerical values of weight and mass of a given object are equal when expressed in the same units.

To avoid confusion, the slug is sometimes used as the unit of mass. This is the mass which weighs 32 pounds at sea level. Its relationship to pounds weight and pounds force and the advantage of its use will be discussed in more detail later in this chapter. Also to be discussed are the metric force units of dynes and newtons. At this point, however, it can be said that at sea level a mass of 1 gram (gm) exerts a downward force of 980 dynes due to gravity, and that 1 kilogram (kg) exerts a downward force of 9.8 newtons. Since 1 kg = 1,000 gm, a kilogram exerts a force of 1,000 × 980 dynes or 980,000 dynes, which is equal to 9.8 newtons. Thus 1 newton = 100,000 dynes.

To relate the newton to the English system, 1 newton equals 0.2247 pound force, or 1 pound force equals 4.448 newtons. Also, the mass unit of 1 slug equals the mass of approximately 14.6 kilograms, so 1 kilogram of mass is approximately 0.0686 slug.

Conversion between weight units of the metric system is simple since it is only a matter of moving the decimal point: 1,000 milligrams (mg) = 1 gm; 1,000 gm = 1 kg; and 1,000 kg = 1 metric ton. The English system requires more effort, since the pound is divided into 16 ounces, and the ounce into 16 drams. The "short ton" is 2,000 pounds, while the "long ton" is 2,240 pounds. The metric ton is fairly close to the "long ton", converting to 2,205 pounds.

Derived Units

Units based on combinations of two or three fundamental units can always be expressed as some combination of these units. The watt (unit of power) could be written as joules (unit of work) per second. The joule in turn could be expressed as newtons (force) times meters (distance) and the watt then becomes newton-meters per second. Likewise the unit of horsepower could be expressed in foot-pounds per second. Although there are conversion factors between derived units of the English system and the metric system, fundamental units of the two systems are not combined. For instance, if force is given in pounds and distance in meters, one or the other must be changed before combining them to get work units.

SPEED AND VELOCITY.–One example of a derived unit is the knot, a unit of speed. This unit combines the nautical mile as the unit of distance and the hour as the unit of time, and is derived by dividing the distance traveled by the time required. Thus, if a ship traveled at a constant rate for 15 minutes (0.25 hr) and moved a distance of 6 nautical miles, its speed would be 6/0.25 or 24 knots. The rate of travel (speed) may also be used to solve for distance traveled when time is known. If the above ship traveled 24 knots for 3 hours, it would move 72 nautical miles. Likewise, the time required for moving a certain distance may be determined when the speed is known. A move of 36 nautical miles traveling at 24 knots would require 36/24 = 1.5 hours, or 1 hour 30 minutes.

Very often speed is expressed with two fundamental units such as miles per hour, kilometers per hour, or feet, inches, meters or centimeters per minute or per second. Conversion is a matter of replacement of one unit by its equivalent in another unit. For example, a speed of 60 miles per hour (60 mph) may be converted to feet per second by replacing the mile with 5,280 feet and the hour with 3,600 seconds. Thus a speed of 60 mph = 60 (5,280 ft/3,600 sec)= 88 feet per second.

Table 3-3 gives the conversion factors between meters per second, feet per second, kilometers per hour, miles per hour, and knots.

The terms "speed" and "velocity" are sometimes used as having the same meaning. However, velocity is a vector quantity–that is, it is speed in a given direction. Thus, a car may move around a circular path with a constant speed while its velocity is continuously changing. When a body moves with constant speed along a straight line whose direction is specified, it is customary to speak of its velocity (which is numerically equal to its speed). Moving along a curved path or along a straight path with no reference being made to direction, it is proper to speak of its speed.

WORK AND ENERGY.–Units of work and energy, also derived units, are the product of the units of force and distance. In the cgs system, the erg is the work done by a force of 1 dyne acting through a distance of 1 centimeter. The joule is the unit of work in the mks system where 1 newton acts through a distance of 1 meter. Since 1 newton equals 100,000 dynes and 1 meter equals 100 centimeters, then the joule is equal to 10,000,000 ergs.

In the English system the unit foot-pound is defined as the work done in lifting 1 pound a distance of 1 foot against the force of gravity. Thus the work done in lifting a mass of 5 pounds vertically 4 feet is 5 lb × 4 ft = 20 foot-pounds. (Do not confuse this foot-pound with the one used to measure torque.) Since 1 pound force equals 4.448 newtons, and 1 foot equals 0.3048 meter, then 1 foot-pound is approximately 1.356 joules.

The calorie is the heat energy required to raise the temperature of 1 gram of water 1° Celsius. The Btu (British thermal unit) is the heat energy required to raise the temperature of 1 pound of water 1° Fahrenheit, and is equivalent to 252 calories (and, incidentally, to 777.8 foot-pounds of mechanical energy).

POWER.–All units of power include measurements of force, distance, and time, because power equals work (which is force times distance) divided by time. The watt is the unit of

Table 3-3.–Conversion factors for speed and velocity.

Speed	m/sec	ft/sec	km/hr	mi/hr	knots
1 m/sec =	1	3.281	3.6	2.24	1.94
1 ft/sec =	0.3048	1	1.0973	0.6818	0.5921
1 km/hr =	0.27778	0.9113	1	0.6214	0.5396
1 mi/hr =	0.44704	1.4667	1.6093	1	0.8684
1 knot =	0.5148	1.689	1.853	1.152	1

power frequently used with electrical units, but is also the rate of doing 1 joule of work in 1 second. Thus if a force of 5 newtons acts through a distance of 12 meters in 3 seconds the power required is $P = \frac{5 \times 12}{3} = 20$ watts. If the same work is to be done in 2 seconds, 30 watts will be required.

The horsepower is a larger unit of power and is equal to 550 foot-pounds per second, or 746 watts; therefore, 1 foot-pound per second is 746/550 watts, or about 1.356 watts.

OTHER UNITS.–To further illustrate the complexity of the magnitude category, consider only a few common examples of measurement dealing with magnitude: weight, distance, temperature, voltage, size, loudness, brightness, etc.; then consider measurements based on combinations of magnitude: density (weight per unit volume), pressure (force per unit area), thermal expansion (increase in size per degree change in temperature), etc. In addition, measurements combine categories: The flow of liquids is measured in volume per unit of time, speed is measured in distance per unit of time, rotation is measured in revolutions per minute, frequency is expressed in cycles per second, (hertz) and so on indefinitely.

The importance of measurement and the necessity of selecting the proper measurement cannot be overemphasized. Several systems of measurement further complicate matters. For example, distance may be measured in feet or in meters; weight in pounds or in kilograms; capacity in quarts or in liters; temperature in degrees Fahrenheit, Celsius, Rankine, or Kelvin; density in pounds per cubic foot or in grams per cubic centimeter; angles in degrees or in radians; etc.

MATTER AND ENERGY

MATTER may be defined basically as "anything that occupies space and has weight or mass." It exists naturally in three states–solid, liquid, or gas. All matter is composed of small particles called molecules. Matter may be changed or combined by various methods–physical, chemical, or nuclear. Matter has many properties; properties possessed by all forms of matter are called general properties, while those properties possessed only by certain classes of matter are referred to as special properties.

ENERGY may be defined basically as "the capacity for doing work." It may be classified in many ways; but for this discussion, energy will be classified as mechanical, chemical, radiant, heat, light, sound, electrical, or magnetic. Energy is constantly being exchanged from one object to another and from one form to another.

Law of Conservation

Matter may be converted from one form to another with no change in the total amount of matter. Energy may also be changed in form with no resultant change in the total quantity of energy. In addition, a third statement has been added within the past half century: "Although the total amount of matter and energy remains constant, matter can be converted into energy or energy into matter." This statement is known as the law of conservation for energy and matter. The basic mathematical equation which shows the relationship between matter and energy is

$$E = mc^2$$

where E represents the amount of energy, m represents the amount of matter (mass), and c represents the velocity of light.

From the equation it may be seen that the destruction of matter creates energy, and that the creation of matter requires expenditure of energy. From this observation it may be implied that a given quantity of matter is the equivalent of some amount of energy. In common usage it is usually stated that matter "possesses" energy.

General Properties of Matter

Matter in all forms possesses certain properties. In the basic definition it has been stated that matter occupies space and has mass. Those two ideas contain most, if not all, of the general properties of matter.

SPACE.–The amount of space occupied by, or enclosed within, the bounding surfaces of a body is called volume. In the study of physics, this concept must be somewhat modified in order to be completely accurate. As stated previously, matter may appear as a solid, as a liquid, or as a gas–each having special properties. In a later section of this chapter it will be shown that for even a specific substance the volume may vary with changes in circumstances. It will also be shown that liquids and solids tend to retain their volume when physically moved from one container to another; gases tend to assume the volume of the container.

It will be discussed at some length later that all matter is composed of atoms and molecules. In order to clarify our concept of "occupying space," we must deal with these minute particles of matter, which are in turn composed of still smaller particles separated from each other by empty space (which contains no matter). This idea is used to explain two general properties of matter–impenetrability and porosity.

Two objects cannot occupy the same space at the same time; this is known as the "impenetrability of matter." The actual space occupied by the individual subatomic particles cannot be occupied by any other matter. The impenetrability of matter may, at first glance, seem invalid when a cup of salt is poured into a cup of water–the result is considerably less than two cups of salt water. However, matter has an additional general property called "porosity" which explains this apparent loss of volume: The water simply occupies space between particles of salt. Porosity is present in all material–but to an extremely wide range of degree. Generally, gases are extremely porous, liquids only slightly so; solids vary over a wide range, from the sponge to the steel ball.

INERTIA.–Every object tends to maintain a uniform state of motion. A body at rest never starts to move by itself; a body in motion will maintain its speed and direction unless it is caused to change. In order to cause a body to deviate from its condition of uniform motion, a push or a pull must be exerted on it. This requirement is due to that general property of all matter known as INERTIA.

The greater the tendency of a body to maintain uniform motion, the greater its inertia. The quantitative measure of inertia is the MASS of the body.

ACCELERATION.–Any change in the state of motion of a body is known as acceleration, and the cause which produces it is called an accelerating force. Acceleration is the rate of change in the motion of a body, and may represent either an increase or a decrease in speed and/or a change in direction of motion.

The amount of acceleration is stated as the change of velocity divided by the time required to make the change. For example, if a car traveling 15 mph increased its speed to 45 mph in 4 seconds, the 30-mph increase divided by 4 seconds gives 7.5 miles per hour per second as its acceleration. By converting the 30 mph to 44 feet per second, the acceleration could be expressed as 11 feet per second per second, or as 11 ft/sec^2.

FORCE.–Force is the action or effect on a body which tends to change the state of motion of the body acted upon. A force may tend to move a body at rest; it may tend to increase or decrease the speed of a moving body; or it may tend to change the body's direction of motion. The application of a force to a body does not necessarily result in a change in the state of motion; it may only TEND to cause such a change.

A force is any push or pull which acts on a body. Water in a can exerts a force on the sides and bottom of the can. A tug exerts a push or a pull (force) on a barge. A man leaning against a bulkhead exerts a force on the bulkhead.

In the above examples, a physical object is exerting the force and is in direct contact with the body upon which the force is being exerted. Forces of this type are called contact forces. There are other forces, which act through empty space without contact—in some cases without even seeming to have any mass associated with them. The force of gravity exerted on a body by the earth—known as the weight of the body—is an example of a force that acts on a body through empty space and without contact. Such a force is known as an action-at-a-distance force. Electric and magnetic forces are other examples of these action-at-a-distance forces. The space through which these action-at-a-distance forces are effective is called a force field.

Force is a VECTOR quantity; that is, it has both direction and magnitude. A force is completely described when its magnitude, direction, and point of application are given. In a force vector diagram, the starting point of the line represents the point of application of the force.

Any given body, at any given time, is subjected to many forces. In many cases, all these forces may be combined into a single RESULTANT force, which may then be used to determine the total effect on the body.

Each body of matter in the universe attracts every other body with a force which is directly proportional to the mass of the bodies and inversely proportional to the square of the distance between them. This force is called the UNIVERSAL FORCE OF GRAVITATIONAL ATTRACTION. Since every body exerts this force on every other body, when considering the forces acting on a single body, it is an almost universal practice to resolve all gravitational forces into a single resultant. At or near the surface of the earth, this becomes a fairly simple process—due to its extremely large mass, the earth exerts such a large gravitational attraction that it is entirely practical to ignore all other such attractions and merely use the earth's gravitational attraction as the resultant.

Although gravitational attraction is exerted by each body on the other, in those cases where there is a great difference in the mass of two bodies, it is usually more convenient to consider the force as being exerted by the larger mass on the smaller mass. Thus, it is commonly stated that the earth exerts a gravitational force of attraction on a body. The gravitational attraction exerted by the earth on a body is called GRAVITY

The gravitational force exerted by the earth on a body is called the WEIGHT of that body, and is expressed in force units. In the English system, force is expressed in pounds. If a body is attracted by a gravitational force of 160 pounds, the body is said to weigh 160 pounds. The gravitational force between two bodies decreases as the distance between them increases; therefore, a body weighs less a mile above the surface of the ocean than it weighs at sea level; it weighs more a mile below sea level.

Density and Specific Gravity

The DENSITY of a substance is its weight per unit volume. A cubic foot of water weighs 62.4 pounds; the density of water is 62.4 pounds per cubic foot. (In the metric system the density of water is 1 gram per cubic centimeter.)

The SPECIFIC GRAVITY (S.G.) of a substance is the ratio of the density of the substance to the density of water—

$$\text{S.G.} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Specific gravity is not expressed in units but as a pure number. For example, if a substance has a specific gravity of 4, 1 cubic foot of the substance weighs 4 times as much as a cubic foot of water—62.4 times 4 or 249.6 pounds. In metric units, 1 cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4 or 4 grams. (Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density.)

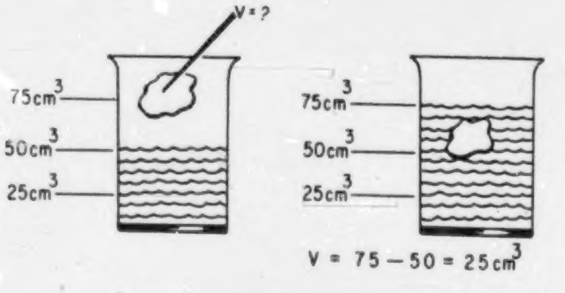
Specific gravity and density are independent of the size of the sample under consideration, and depend only upon the substance of which the sample is made. See table 3-4 for typical values of specific gravity for various substances.

A great deal of ingenuity is often needed to measure the volume of irregularly shaped bodies. Sometimes it is practical to divide a body into a series of regularly shaped parts and then apply

Table 3-4.—Typical values of specific gravity.

Substance	Specific gravity
Aluminum	2.7
Brass	8.6
Copper	8.9
Gold	19.3
Ice	0.92
Iron	7.8
Lead	11.3
Platinum	21.3
Silver	10.5
Steel	7.8
Mercury	13.6
Ethyl alcohol	0.81
Water	1.00

the rule that the total volume is equal to the sum of the volumes of all individual parts. Figure 3-1 demonstrates another method of measuring the volume of small irregular bodies. The volume of water displaced by a body submerged in water is equal to the volume of the body.



AT. 20

Figure 3-1.—Measuring the volume of an irregular object.

A somewhat similar consideration is possible for floating bodies. A floating body displaces its own weight of liquid. This may be proved by filling a container to the brim with liquid, then gently lowering the body to the surface of the liquid and catching the liquid that flows over the brim. Weighing the liquid displaced and the original body will prove the truth of the statement.

Pressure and Total Force

Pressure and force, while closely related topics, are not the same thing. A weight of 10 pounds resting on a table exerts a force of 10 pounds. However, the shape of the weight must be taken into consideration to determine the effect of the weight. If the weight consists of a thin sheet of steel resting on a flat surface, the effect is quite different than if the same sheet of steel were resting on a sharp corner.

Pressure is concerned with the distribution of a force with respect to the area over which that force is distributed. Pressure is defined as the force per unit of area, or $P = F/A$. A flat pan of water with a bottom area of 24 square inches and a total weight of 72 pounds exerts a total force of 72 pounds, or a pressure of 72/24 or 3 pounds per square inch, on the flat table. If the pan is balanced on a block with a surface area of 1 square inch, the pressure is 72/1 or 72 pounds per square inch. An aluminum pan with a thin bottom is suitable for use on a flat surface, but may be damaged if placed on the small block.

This concept explains why a sharp knife cuts more easily than a dull one. The smaller area concentrates the applied force (increases the pressure) and penetrates more easily. For hydraulic applications, the relationship between pressure and force is the basic principle of operation. In enclosed liquids under pressure, the pressure is equal at every point on the surfaces of the enclosing container, and therefore the force on a given surface is dependent on the area.

Kinetic Energy

Moving bodies possess energy because, by virtue of their mass in motion, they are capable of doing work. The energy of mass in motion is called KINETIC energy, and may be expressed by the equation

$$\text{Kinetic energy} = 1/2\ mv^2$$

where m represents the mass of the body, and v is the velocity of its motion. When the moving body is stopped, it loses its kinetic energy. The energy is not destroyed, but is merely converted into other forms of energy, such as heat and POTENTIAL energy. It is important to remember that bodies at rest also possess energy by virtue of their position.

STRUCTURE OF MATTER

All matter is composed of atoms, and these atoms are, in turn, composed of smaller subatomic particles. The subatomic particles of major interest in elementary physics are the electron, the proton, and the neutron. They may be considered electrical in nature, with the proton representing a positive charge, the electron representing a negative charge, and the neutron being neutral (neither positive nor negative). Although in general the composition of matter follows a consistent pattern for all atoms, the detailed arrangement of subatomic particles is different for each distinct substance. It is the combination and arrangement of the subatomic particles which imparts the distinguishing chemical and physical characteristics to a substance.

The protons and the neutrons of an atom are closely packed together in a nucleus (core), with the electrons revolving around the nucleus. Atoms are normally considered to be electrically neutral—that is, they normally contain an equal number of electrons and protons; but this condition does not actually prevail under all circumstances. Atoms which contain an equal number of electrons and protons are called balanced atoms; those with an excess or a deficiency of electrons are called "ions."

The proton and the neutron have approximately the same mass, which is approximately 1,836 times the mass of an electron. In any atom, nearly all the mass is contained in the nucleus. It may be assumed that under normal conditions any change in the composition of the atom would involve a change in the number or arrangement of the electrons (due to the smaller mass, electrons are more easily repositioned than are protons). This assumption is generally correct—the most notable exception being in the field of nuclear physics, or nucleonics. In chemistry and in general physics, (including electricity and electronics), it is the electron complement that is of major concern.

ELEMENTS

The word element is used to denote any one of about 100 substances which comprise the basic substance of all matter. Two or more elements may combine chemically to form a compound; any combination which does not result in a chemical reaction between the different elements is called a mixture. The atom is the smallest unit that exhibits the distinguishing characteristics of an element. An atom of any one element differs from an atom of any other element in the number of protons in the nucleus. All atoms of a given element contain the same number of protons. Thus, it may be seen that the number of protons in the nucleus determines the type of matter.

The various elements are frequently tabulated according to the number of protons. The number of protons in the nucleus of the atom is referred to as the atomic number of the element.

Nucleus

The study of the nucleus of the atom, known as nucleonics or nuclear physics, is the subject of extensive modern investigation. Experiments on nuclei usually involve the bombardment of the nucleus of an atom, using various types of nuclear particles. By this method the composition of the nucleus is changed, usually resulting in the release of energy. The change to the nucleus may occur as an increase or a decrease in the number of protons and/or neutrons.

If the number of protons is changed, the atom has become an atom of a different element. This process, called "transmutation," is the process sought by the alchemists of the middle ages in their attempts to change various metals into gold. Scientists of that period believed transmutation could be accomplished by chemical means–hence the impetus given to the development of chemistry.

If, on the other hand, only the number of neutrons in the nucleus is changed, the atom remains an atom of the same element. Although all the atoms of any particular element have the same number of protons (atomic number), atoms of certain elements may contain various numbers of neutrons. Hydrogen (the sole exception to the rule that all atoms are composed of three kinds of subatomic particles) normally contains a single proton and a single electron–and no neutrons. However, some hydrogen atoms do contain a neutron. Such atoms (although they are atoms of hydrogen) are known as deuterium, or "heavy hydrogen." (They are called "heavy" because the addition of the neutron has approximately doubled the weight of the atom. Deuterium figured prominently in the research which led to the development of nuclear energy and the atomic bomb.) The atomic weight of an atom is an indication of the total number of protons and neutrons in the atomic nucleus.

Atoms of the same element but which have different atomic weights are called isotopes. Nearly all elements have several isotopes; some are very common, and some are very rare. A few of the isotopes occurring naturally and most of those produced by nuclear bombardment are radioactive or have unstable nuclei. These unstable isotopes undergo a spontaneous nuclear bombardment which eventually results in either a new element or a different isotope of the same element. The rate of spontaneous radioactive decay is measured by "half-life" which is the time required for one-half the atoms of a sample of radioactive material to change (by spontaneous radioactive decay) into a different substance. **Uranium, after a few billion years and** several substance changes, becomes lead.

Electron Shells

The physical and chemical characteristics of an element are determined by the number and distribution of electrons in the atoms of that element. The electrons are arranged in successive groups of electron shells of rotation around the nucleus; each shell can contain no more than a specific number of electrons. An INERT element (that is, one of the few gas elements which do not combine chemically with any other element) is a substance in which the outer **electron shell of each atom is completely filled.** In all other elements, one or more electrons are missing from the outer shell. An atom with only one or two electrons in its outer shell can be made to give up those electrons; an atom whose outer shell needs only one or two electrons to be completely filled can accept electrons from another element which has one or two "extras."

The concept of "needed" or "extra" electrons arises from the basic fact that all atoms have a tendency toward completion (filling) of the outer shell. An atom whose outer shell has only two electrons may have to collect six additional ones (no easy task, from an energy standpoint) in order to have the eight required for that shell to be full. A much easier way to achieve the same objective is to give up the two electrons in the outer shell and let the full shell next to it serve as the new outer shell. In chemical terminology, this concept is called valence, and is the prime determining factor in predicting chemical combinations.

COMPOUNDS AND MIXTURES

Under certain conditions, two or more elements can be brought together in such a way that they unite chemically to form a COMPOUND. The resulting substance may differ widely from any of its component elements; for example, ordinary drinking water is formed by the chemical union of two gases–hydrogen and oxygen. When a compound is produced, two or more atoms of the combining elements join chemically to form the MOLECULE that is typical of the new compound. The molecule is the smallest unit that exhibits the distinguishing characteristics of a compound.

The combination of sodium and chlorine to form the chemical compound sodium chloride (common table salt) is a typical example of the formation of molecules. Sodium is a highly caustic poisonous metal containing eleven electrons; its outer shell consists of a single electron, which may be considered "extra" (a valence of +1). Chlorine, a highly poisonous gas with seventeen electrons, "lacks" a single electron (has a valence of −1) to fill its outer shell. When the atom of sodium gives up its extra electron, it becomes a positively charged ion. (It has lost a unit of negative charge.) The chlorine, having taken on this extra unit of negative charge (electron) to fill its outer shell, becomes a negative ion. Since opposite electric charges attract, the ions stick together to form a molecule of the compound sodium chloride.

The attracting force which holds the ions together in the molecular form is known as the "valance bond," a term which is frequently encountered in the study of transistors.

Note that in the chemical combination, there has been no change in the nucleus of either atom; the only change has occurred in the distribution of electrons between the outer shells of the atoms. Also note that the total number of electrons has not changed, although there has been a slight redistribution. Therefore, the molecule is electrically neutral, and has no resultant electrical charge.

Not all chemical combinations of atoms are on a one-for-one basis. In the case of drinking water, two atoms of hydrogen (valence of + 1) are required to combine with a single atom of oxygen (valence of −2) to form a single molecule of water. Some of the more complex chemical compounds consist of many elements with various numbers of atoms of each. All molecules, like all atoms, are normally considered to be electrically neutral. There are some exceptions to this rule, however, with specific cases of interest being the chemical activity in batteries.

Elements or compounds may be physically combined without necessarily undergoing any chemical change. Grains of finely powdered iron and sulfur stirred and shaken together retain their own identity as iron or sulfur. Salt dissolved in water is not a compound; it is merely salt dissolved in water. Each chemical substance retains its chemical identity, even though it may undergo a physical change. This is the typical characteristic of a MIXTURE.

STATES OF MATTER

In their natural condition, forms of matter are classified and grouped in many different ways. One such classification is in accordance with their natural state—solid, liquid, or gas. This classification is important because of the common characteristics possessed by substances in one group which distinguish them from substances in the other groups. However, the usefulness of the classification is limited by the fact that most substances can be made to assume any of the three forms.

In all matter, the molecules are assumed to be in constant motion, and it is the extent of this motion that determines the state of matter. The moving molecular particles in all matter possess kinetic energy of motion. The total of this kinetic energy is considered to be the equivalent of the quantity of heat in a sample of the substance. When heat is added, the energy level is increased, and molecular agitation (motion) is increased. When heat is removed, the energy level decreases, and molecular motion diminishes.

In solids, the motion of the molecules is greatly restricted by the rigidity of the crystalline structure of the material. In liquids, the molecular motion is somewhat less restricted, and the substance as a whole is permitted to "flow." In gases, molecular motion is almost entirely random—the molecules are free to move in any direction and are almost constantly in collision both among themselves and with the surfaces of the container.

This topic and some of its more important implications are discussed in detail under the heading "Heat" in a later section of this chapter.

Solids

The outstanding characteristic of a solid is the tendency to retain its size and shape. Any change in these values requires the exchange of energy. The common properties of a solid are cohesion and adhesion, tensile strength, ductility, malleability, hardness, brittleness, and elasticity. Ductility is a measure of the ease with which the material can be drawn into a wire. Malleability refers to the ability of some materials to assume new shape when pounded. Hardness and brittleness are self-explanatory terms. The remaining properties are discussed in more detail in the following paragraphs.

COHESION AND ADHESION.—Cohesion is the molecular attraction between like particles throughout a body, or the force that holds any substance or body together. Adhesion is the molecular attraction existing between surfaces of bodies in contact, or the force which causes unlike materials to stick together.

Cohesion and adhesion are possessed by different materials in widely varying degree. In general, solid bodies are highly cohesive but only slightly adhesive. Fluids (liquids and gases), on the other hand, are usually quite highly adhesive but only slightly cohesive. Generally a material having one of these properties to a high degree will possess the other property to a relatively low degree.

TENSILE STRENGTH.—The cohesion between the molecules of a solid explains the property called tensile strength. This is a measure of the resistance of a solid from being pulled apart. Steel possesses this property to a high degree, and is thus very useful in structural work. When a break does occur, the pieces of the solid cannot be stuck back together because merely pressing them together does not bring the molecules into close enough contact to restore the molecular force of cohesion. However, melting the edges of the break (welding) allows the molecules on both sides of the break to flow together, thus bringing them once again into the close contact required for cohesion.

ELASTICITY.—If a substance will spring back to its original form after being deformed, it has the property of elasticity. This property is desirable in materials to be used as springs. Steel and bronze are examples of materials which exhibit this property.

Elasticity of compression is exhibited to some degree by all solids, liquids, and gases; the closeness of the molecules in solids and liquids makes them hard to compress, but gases are easily compressed because the molecules are farther apart.

Liquids

The outstanding characteristic of a liquid is its tendency to retain its own volume while assuming the shape of its container; thus a liquid is considered almost completely flexible and highly fluid.

Liquids are practically incompressible; applied pressure is transmitted through them instantaneously, equally, and undiminished to all points on the enclosing surfaces. Hydraulic apparatus can be used to increase or to decrease input forces, thus providing an action similar to that of mechanical advantage in mechanical systems. Because of these properties, hydraulic servomechanisms have advantages as well as disadvantages and limitations when compared with other systems.

The fluidity of hydraulic liquids permits the component parts of the system to be placed conveniently at widely separated points when necessary. Hydraulic power units can transmit energy around corners and bends without the use of complicated gears and levers. They operate with a minimum of slack and friction, which are often excessive in mechanical linkages. Uniform action is obtained without vibration, and the operation of the system remains largely unaffected by variations in load. The accumulator (which provides the necessary pressurization of the system to furnish practically instantaneous response) can be pressurized during periods of nonaction, thus eliminating the "buildup time" characteristic of electric servos.

However, the hydraulic hoses which transmit the fluid from unit to unit are bulky and heavy compared to electric wiring. Many of the hydraulic fluids in common usage are messy and constitute safety hazards. They contribute to the danger of slipping, they cause deterioration of the insulation on electric wiring, they conduct electricity and thus increase the hazards of short circuiting, and some are flammable.

Gases

The most notable characteristics of a gas are its tendency to assume not only the shape but also the volume of its containers, and the definite relationship that exists between the volume, pressure, and temperature of a confined gas.

The ability of a gas to assume the shape and volume of its container is the result of its extremely active molecular particles, which are free to move in any direction. Cohesion between molecules of a gas is extremely small, so the molecules tend to separate and distribute themselves uniformly throughout the volume of the container. In an unpressurized container of liquid, pressure is exerted on the bottom and the sides of the container up to the level of the liquid. In a gas, however, the pressure is also exerted against the top surface, and the pressure is equal at all points on the enclosing surfaces.

The relationship of volume, pressure, and temperature of confined gas are explained by Boyle's law, Charles' law, and the general law for gases.

Many laboratory experiments based on these laws make use of the ideas of "standard pressure" and "standard temperature." These are not natural standards, but are standard values selected for convenience in laboratory usage. Standard values are generally used at the beginning of an experiment, or when a temperature or a pressure is to be held constant. Standard temperature is 0° C, the temperature at which pure ice melts. Standard pressure is the pressure exerted by a column of mercury 760 millimeters high. In many practical uses these standards must be changed to other systems of measurement.

All calculations based on the laws of gases make use of "absolute" temperature and pressure. These topics require a somewhat more detailed explanation.

GAS PRESSURE.–Gas pressure may be indicated in either of two ways–absolute pressure or gage pressure. Since the pressure of an absolute vacuum is zero, any pressure measured with respect to this reference is referred to as "absolute pressure." In the present discussion, this value represents the actual pressure exerted by the confined gas.

At sea level the average atmospheric pressure is approximately 14.7 pounds per square inch (psi). This pressure would, in a mercurial barometer, support a column of mercury 760 millimeters in height. Thus, normal atmospheric pressure is the standard pressure mentioned previously.

However, the actual pressure at sea level varies considerably; and the pressure at any given altitude may differ from that at sea level. Therefore, it is necessary to take into consideration the actual atmospheric pressure when converting absolute pressure to gage pressure (or vice versa).

When a pressure is expressed as the difference between its absolute value and that of the local atmospheric pressure, the measurement is designated "gage" pressure, and is usually expressed in "pounds per square inch gage" (psig). Gage pressure may be converted to absolute pressure by adding the local atmospheric pressure to the gage pressure.

ABSOLUTE ZERO.–Absolute zero, one of the fundamental constants of physics, is usually expressed in terms of the Celsius scale. Its most predominant use is in the study of the kinetic theory of gases. In accordance with the kinetic theory, if the heat energy of a given gas sample could be progressively reduced, some temperature should be reached at which the motions of the molecules would cease entirely. If accurately determined, this temperature could then be taken as a natural reference, or a true "absolute zero" value.

Experiments with hydrogen (making use of the proven correlation with the volume, temperature, and pressure of gases and by calculations based on this correlation) indicated that if a gas were cooled to −273.16° C (used as −273° for most calculations), all molecular motion would cease and no additional heat could be extracted from the substance. It is believed that at this point both the volume and the pressure of gas would shrink to zero.

When temperatures are measured with respect to the absolute zero reference, they are said to be expressed in the absolute, or Kelvin, scale. Thus, absolute zero may be expressed either as 0° K or as −273° C.

BOYLE'S LAW.–The English scientist Robert Boyle was among the first to study what he called the "springiness of air." By direct measurement he discovered that when the temperature of an enclosed sample of gas was kept constant and the pressure doubled, the volume was reduced to half the former value; as the applied pressure was decreased, the resulting volume increased. From these observations, he concluded that for a constant temperature the product of the volume and pressure of an enclosed gas remains constant. Boyle's law is normally stated: "The volume of an enclosed dry gas varies inversely with its pressure, provided the temperature remains constant."

In equation form, this relationship may be expressed either

$$V_1 P_1 = V_2 P_2 \text{, or}$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where V_1 and P_1 are the original volume and pressure, and V_2 and P_2 are the revised volume and pressure.

CHARLES' LAW.–The French scientist Jacques Charles provided much of the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law may be expressed

$$V_1 T_2 = V_2 T_1 \text{, or}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where V_1 and V_2 refer to the original and final volumes, and T_1 and T_2 indicate the corresponding absolute temperatures.

Since any change in the temperature of a gas causes a corresponding change in volume, it is reasonable to expect that if a given sample of a gas were heated while confined within a given volume, the pressure should increase. By actual experiment, it was found that the increase in pressure was approximately 1/273 of the 0° C pressure for each 1° C increase. Because of this fact, it is normal practice to state this relationship in terms of absolute temperature. In equation form, this part of the law becomes

$$P_1 T_2 = P_2 T_1 \text{, or}$$

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

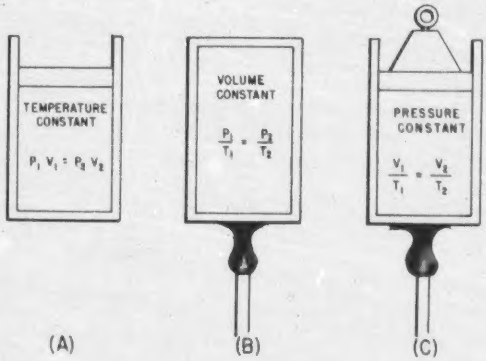
In words, this equation states that with a constant volume, the absolute pressure of a gas varies directly with the absolute temperature.

GENERAL GAS LAW.–The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 3-2. Boyle's law is expressed in (A) of the figure; while the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. This expression is called the GENERAL GAS EQUATION, a very useful form of which is given by the following equation. (NOTE: The capital P and T signify absolute pressure and temperature, respectively.)

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

It can be seen by examination of figure 3-2 that the three equations are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2 and both can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).



AT. 21

Figure 3-2.–The general gas law.

It should be understood that the general gas law applies only when one of the three measurements remains constant. When a gas is compressed, the work of compression is done upon the gas. Work energy is converted to heat energy in the gas so that dynamical heating of the gas takes place. Experiments have shown that when air at 0° C is compressed in a nonconducting cylinder to half its original volume its rise in temperature is 90° C, and when compressed to one-tenth, its rise is 429° C.

The general gas law applies with exactness only to "ideal" gases in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes.

MECHANICS

Mechanics is that branch of physics which deals primarily with the ideas of force, mass, and motion. Normally considered the fundamental branch of physics, it deals with matter. Many of its principles and ideas may be seen, measured, and tested. Since all other branches of physics are also concerned (to some extent at least) with force, mass, and motion, a thorough understanding of this section will aid in the understanding of later sections of this chapter.

FORCE, MASS, AND MOTION

Each particle in a body is acted upon by gravitational force. However, in every body there is one point at which a single force, equal to the gravitational force and directed upward, would sustain the body in a condition of rest. This point is known as the CENTER OF GRAVITY, and represents the point at which the entire mass of the body appears to be concentrated. The gravitational effect is measured from the center of gravity. In symmetrical objects of uniform mass, this is the geometrical center. In the case of the earth, the center of gravity is near the center of the earth.

When considering the motion of a body, it is usually convenient to describe the path followed by the center of gravity. The natural tendency of a moving body is to move in a manner so that the center of gravity travels in a straight line. Movement of this type is called LINEAR motion.

Some moving bodies, however, do not move in a straight line, but describe an arc or a circular path. Circular motion falls into two general classes—rotation and revolution.

Since objects come in many different shapes and in order to discuss rotary and revolutionary motion, it becomes necessary to consider the location of the center of gravity with respect to the body. Refer to figure 3-3 for the following discussion.

In (A), the center of gravity of a ball coincides with the physical center of the ball. However, in the flat washer (B), the center of gravity does not coincide with any part of the object, but is located at the center of the hollow space inside the ring. In irregularly shaped bodies, the center of gravity may be difficult to locate exactly.

If the body is completely free to rotate, the center of rotation coincides with the center of gravity. On the other hand, the body may be restricted in such a manner that rotation is about some point other than the center of gravity. In this event, the center of gravity revolves around the center of rotation. These conditions are illustrated in figure 3-4.

In general usage, the gyro rotor (A) is said to ROTATE about its axis, and the ball (B) is said to REVOLVE about a point at the center of its path.

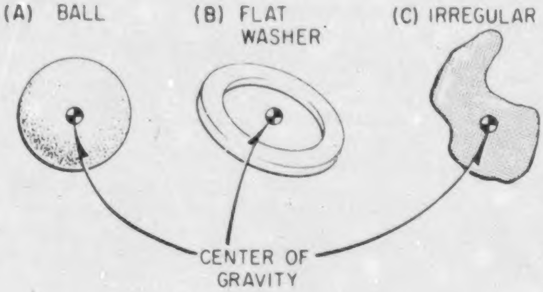


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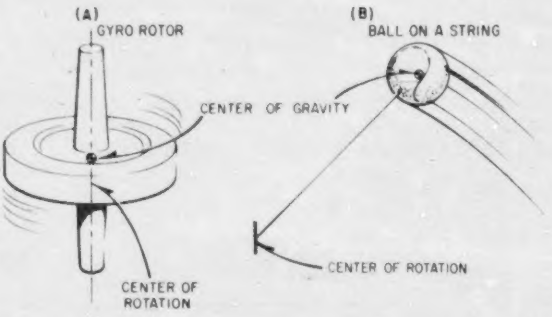
Figure 3-3.—Center of gravity in various bodies.



AT.23

Figure 3-4.–Center of gravity and center of rotation.

MASSES IN MOTION

MOTION may be defined as the "act or process of changing place or position." The "state of motion" refers to the amount and the type of motion possessed by a body at some definite instant (or during some interval) of time. A body at rest is not changing in place or position; it is said to have zero motion, or to be motionless.

The natural tendency of any body at rest is to remain at rest; a moving body tends to continue moving in a straight line with no change in speed or direction. A body which obeys this natural tendency is said to be in uniform motion.

Any change in the speed or direction of motion of a body is known as acceleration and requires the application of some force. The acceleration of a body is directly proportional to the force causing that acceleration; acceleration depends also upon the mass of the body. The greater mass of a lead ball makes it harder to move than a wood ball of the same diameter. The wood ball moves farther with the same push.

These observations point to a connection between force, mass, and acceleration, and indicate that the acceleration of a body is directly proportional to the force exerted on that body and inversely proportional to the mass of that body. In mathematical form, this relationship may be expressed as

$$a = \frac{F}{m}$$

or, as it is more commonly stated: Force is equal to the product of the mass and acceleration ($F = ma$).

Acceleration Due to Gravity

The small letter g used in formulas for solving for weight when mass is known, ($W = mg$) represents the acceleration of a body in free fall, neglecting any friction. This can happen only in a vacuum. At sea level near the Equator, g has the approximate values of 32 ft/sec^2 in the fps system, 980 cm/sec^2 in the cgs system and 9.8 m/sec^2 in the mks system. Transposing the formula $W = mg$ to solve for m, the absolute units of mass of a body may be determined when its weight is known. Thus, when we use the formula stated in Newton's Second Law of Motion–force = mass times acceleration–to find what force would be necessary to give a one-ton car an acceleration of 8 ft/sec^2, we substitute $\frac{w}{g}$ for mass so that force = $\frac{2{,}000 \text{ lb}}{32 \text{ ft/sec}^2} \times 8$ ft/sec^2 = 500 pounds.

The slug, mentioned earlier, is a mass which would be accelerated 1 foot per second per second by a force of 1 pound. Since any mass falling freely under the pull of gravity has an acceleration of 32 ft/sec^2, this acceleration imparted to 1 slug could only be caused by a force of 32 pounds. In other words, a slug of mass weighs 32 pounds.

Example: A wagon weighing 160 pounds (5 slugs) stands at rest on a level surface. Neglecting friction, what acceleration will be given by a force of 20 pounds?

$$a = \frac{F}{m} = \frac{20 \text{ lb}}{5 \text{ slugs}} = 4 \text{ ft/sec}^2$$

The advantage of using absolute units for mass is more apparent when considering bodies in motion far removed from the earth where the pull of gravity is reduced or even zero. The 5-slug wagon would experience the same acceleration when acted on by the given force, even though its weight be greatly reduced.

In the metric system the newton is the force which would cause a mass of 1 kg to be accelerated 1 m/sec^2. Since g = 9.8 m/sec^2, then 1 kg mass exerts a force of 9.8 newtons due to gravity. A newton is equal to 0.224 lb.

The dyne is the force which would cause a mass of 1 gm to be accelerated 1 cm/sec^2, so 1 gm exerts a force of 980 dynes due to gravity.

If the accelerating force is applied to the center of gravity in such a manner as to accelerate the body with no rotation, it is called a TRANSLATIONAL force. A force applied in such a manner as to cause the body to rotate about a point is called a TORQUE force.

Laws of Motion

Among the most important discoveries in theoretical physics are the three fundamental laws of motion attributed to Newton. Although some of these laws have been used in explanations of various topics earlier in this chapter, they are restated and consolidated at this point to clarify and summarize much of the discussion regarding mechanical physics. This restatement and consolidation are also used to introduce additional aspects involving the applications of basic mechanical principles.

1. Every body tends to maintain a state of uniform motion unless a force is applied to change the speed or direction of motion.
2. The acceleration of a body is directly proportional to the magnitude of the applied force and inversely proportional to the mass of the body; acceleration is in the direction of the applied force.
3. For every force applied to a body, the body exerts an equal force in the opposite direction.

Momentum

Every moving body tends to maintain uniform motion. Quantitative measurement of this tendency is proportional to the mass of the body, and also to its velocity. (Momentum = mass × velocity.) This explains why heavy objects in motion at a given speed are harder to stop than lighter objects, and also why it is easier to stop a given body moving at low speed than it is to stop the same body moving at high speed.

WORK, POWER, AND ENERGY

As defined earlier, energy is the capacity for doing work. In mechanical physics, WORK involves the idea of a mass in motion, and is usually regarded as the product of the applied force and the distance through which the mass is moved (work = force × distance). Thus, if a man raises a weight of 100 pounds to a height of 10 feet he accomplishes 1,000 foot-pounds of work. The amount of work accomplished is the same regardless of the time involved. However, the RATE of doing the work may vary greatly.

The rate of doing work (called POWER) is defined as the work accomplished per unit of time (power = work/time). In the example cited above, if the work is accomplished in 10 seconds, power is being expended at the rate of 100 foot-pounds per second; if it takes 5 minutes (300 seconds), the rate is approximately 3.3 foot-pounds per second.

In the English system of measurements, the unit of mechanical power is called the HORSEPOWER and is the equivalent of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Since energy is readily convertible from one form to another, the work and power measurements based on the conversion of energy must also be readily convertible. As an example, the electrical unit of power is the watt. Electrical energy may be converted into mechanical energy; therefore, electrical power must be convertible into mehcanical power. One horsepower is the mechanical equivalent of 746 watts of electrical power, and is capable of doing the same amount of work in the same time.

The accomplishment of work always involves a change in the type of energy, but does not change the total quantity of energy. Thus, energy applied to an object may produce work, changing the composition of the energy possessed by the object.

Potential Energy

A body is said to have potential energy if by virtue of its position or its state it is able to do work. A wound clock spring and a cylinder of compressed gas both possess potential energy since they can do work in returning to their uncompressed condition. Also, a weight raised above the earth has potential energy since it can do work in returning to the ground. Thus, potential energy results when work has been done against a restoring force. The water in a reservoir above a hydroelectric plant has potential energy regardless of whether the water was placed there by work applied via a pump or by the work done by the sun to lift it from the sea and place it in the reservoir in the form of rain.

Kinetic Energy

The ability of a body to do work by virtue of its MOTION is called its kinetic energy. A rotating wheel on a machine has kinetic energy of rotation. A car moving along the highway has kinetic energy of translation.

For a given mass m, moving in a straight line with a velocity v, the kinetic energy is determined by

$$\text{Kinetic energy} = \frac{1}{2}mv^2 \begin{cases} \text{in ergs when} \begin{cases} \text{m is in grams} \\ \text{v is in cm per sec} \end{cases} \\ \text{in ft-lbs when} \begin{cases} \text{m is in slugs} \\ \text{v is in ft per sec} \end{cases} \end{cases}$$

Example: The kinetic energy of a 3,200-lb car which is traveling at 30 miles per hour can be found by expressing the 3,200 lb as 100 slugs and the 30 mph as 44 feet per second. Inserting these values into the formula gives kinetic energy $= \frac{1}{2} \times 100 \times 44 \times 44 = 96{,}800$ foot-pounds of energy. This amount of kinetic energy is the result of 96,800 foot-pounds of work (plus that to overcome friction) having been applied to the car to get it traveling at the rate of 44 feet per second. The same amount of energy could do the work of lifting the 3,200 pounds vertically a distance of 30.25 feet, and so could have been potential energy if the car had been at rest on an incline and then allowed to coast to a point which is vertically 30.25 feet below its starting point (again neglecting friction).

Efficiency

Provided there is no change in the quantity of matter, energy is convertible with no gain or loss. However, the energy resulting from a given action may not be in the desired form—it may not even be usable in its resultant form. In all branches of physics, this concept is known as EFFICIENCY.

The energy expended is always greater than the energy recovered. An automobile in motion possesses a quantity of kinetic energy dependent on its mass and velocity. In order to stop the car, this energy must be converted into potential energy. When the car comes to rest, its potential energy is considerably less than the kinetic energy it possessed while in motion. The difference, or the "energy lost" is converted into heat by the brakes. The heat serves no useful purpose, so the recovered energy is less than the expended energy—the system is less than 100 percent efficient in converting kinetic to potential energy.

The term efficiency is normally used in connection with work and power considerations to denote the ratio of the input to the output work, power, or energy. It is always expressed as a decimal or as a percent less than unity.

Friction

In mechanical physics, the most common cause for the loss of efficiency is FRICTION. Whenever one object is slid or rolled over another, irregularities in the contacting surfaces interlock and cause an opposition to the force being exerted. Even rubbing two smooth pieces of ice together produces friction, although of a much smaller magnitude than in the case of two rough stones. Friction also exists in the contact of air with all exposed parts of an aircraft in flight.

When a nail is struck with a hammer, the energy of the hammer is transferred to the nail, and the nail is driven into a board. The depth of penetration depends on the momentum of the hammer, the size and shape of the nail, and the hardness of the wood. The larger or duller the nail and the harder the wood, the greater the friction, and therefore the lower the efficiency and less depth of penetration—but the greater the heating of the nail.

Friction is always present in moving machinery, and accounts in part for the fact that the useful work accomplished by the machine is never as great as the energy applied. Work accomplished in overcoming friction is usually not recoverable. Friction can be minimized by decreasing the number of contacting points, by making the contacting areas as small and as smooth as possible, by the use of bearings, or by the use of lubricants.

There are two kinds of friction—sliding and rolling, with rolling friction usually of lower magnitude. Therefore, most machines are constructed so that rolling friction is present rather than sliding friction. The ball bearing and the roller bearing are used to convert sliding friction to rolling friction. A third type, the common (or friction) bearing, utilizes lubricants applied to surfaces which have been made as smooth as possible. Many new types of machines utilize self-lubricating bearings to minimize friction and thus maximize efficiency.

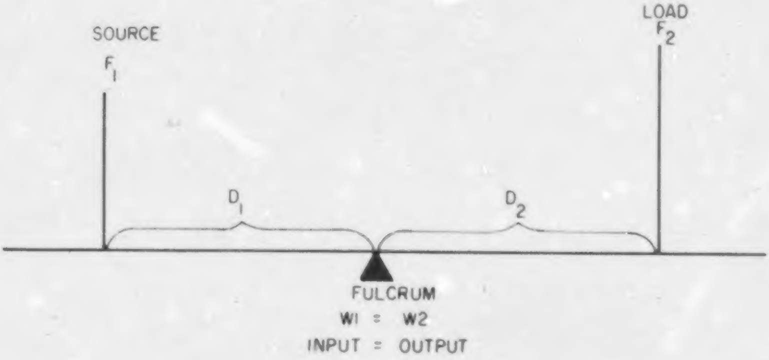
Mechanical Advantage

The concept of mechanical advantage has proved to be one of the great discoveries of science. It permits an increase in force or distance and represents the basic principle involved in levers, block and tackle systems, screws, hydraulic mechanisms, and other work saving devices. However, in the true sense, these devices do not save work, they merely enable humans to accomplish tasks which might otherwise be beyond their capability. For example, a human would normally be considered incapable of lifting the rear end of a truck in order to change a tire; but with a jack, a block and tackle, or a lever, the job can be made comparatively easy.

Mechanical advantage is usually considered with respect to work. Work represents the application of a force through a distance in order to move an object through a distance. Thus, it may be seen that there are two forces involved, each with an appropriate distance. This is illustrated by the simple lever in figure 3-5.

Assuming perfect efficiency, the work input ($F_1 D_1$) is equal to the work output ($F_2 D_2$). Assuming equal distances D_1 and D_2, a force of 10 pounds must be applied at the source in order to counteract a weight of 10 pounds at the load.

By moving the fulcrum nearer the load, less force is required to balance the same load. This is a mechanical advantage of force. If the force is applied in such a manner as to raise the load 1 foot, the source must be moved through a distance greater than 1 foot. Thus, mechanical advantage of force represents a mechanical disadvantage of distance. By moving the fulcrum nearer the source, these conditions are reversed.



AT.24

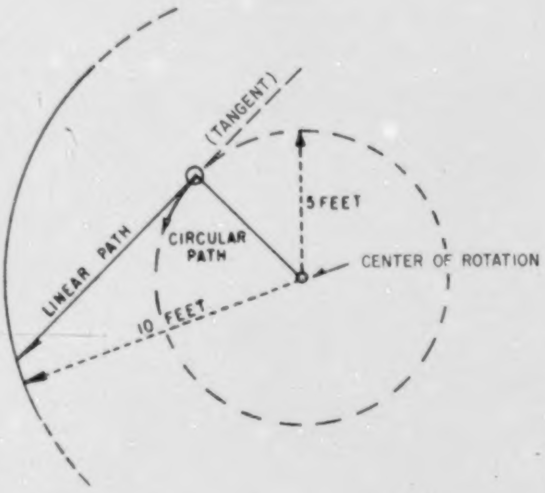
Figure 3-5.—Mechanical advantage.

Since the input work equals the output work (assuming no losses), the mechanical advantage may be stated as a ratio of the force or of the distances. In actual situations, friction results in energy loss and decreased efficiency, thereby requiring an even greater input to accomplish the same work.

REVOLVING BODIES

Revolving bodies represent masses in motion; therefore, they possess all the characteristics (and obey all the laws) associated with moving bodies. In addition, since they possess a specific type of motion, they have special properties and factors which must be taken into consideration.

Revolving bodies travel in a constantly changing direction, so they must be constantly subjected to an accelerating force. Momentum tends to produce linear motion, but this is prevented by application of a force which restrains the object. This restraining force prevents the object from continuing in a straight line, and is known as CENTRIPETAL force. According to Newton's third law of motion, the centripetal force must be opposed by an equal force which tends to produce linear motion. This second force is known as CENTRIFUGAL force. The two forces, their relationships, and their effects are illustrated in figure 3-6.



AT.25

Figure 3-6.—Forces on revolving bodies.

The various forces involved in revolving bodies may be illustrated by use of a ball and string. A slip knot is tied in the center of a 10-foot length of twine so as to shorten the line to 5 feet; a rubber ball is attached to one end of the string. Holding the other end of the line, whirl the ball slowly in a circle. Note that the ball exerts a force against the hand (through the string); and that in order to restrain the ball in its circular path, the hand must exert a force (through the string) on the ball. As the ball is revolved at higher speed, the forces increase, and the ball continues in a circular path. As the rotational velocity of the ball is gradually increased, note the increasing forces.

At some rotational speed, the forces involved become great enough to overcome inertial friction, and the knot slips. At this time, allow the velocity of the rotation to stabilize (stop increasing in rotational velocity, but not slowing down, either), so that the existing conditions may be analyzed. When the knot slips, the ball is temporarily unrestrained and is free to assume linear motion in the direction of travel at that instant (tangent to the circle at the instantaneous position). The ball travels in a straight line until the string reaches its full length; during this time, no force is exerted on or by the hand. As soon as all the slack is taken up, there is a sharp jerk—an accelerating force is exerted in order to change the direction of motion from its linear path into a circular rotation. The ball again assumes rotational motion, but with an increase in radius.

The ball does not make as many revolutions in the same time (rotational velocity is decreased), but it does maintain its former linear velocity. (The kinetic energy and the momentum of the ball have not changed.) Since the change in direction is less abrupt with a large radius than with a small one, less accelerating force is required, and the hand will feel less force. If the ball is then accelerated to the same rotational velocity as immediately prior to the slipping of the knot, the linear velocity of the ball becomes much greater than before; the centripetal and centrifugal forces are much greater, also.

In this example, it has been assumed that the hand is fixed at a point which represents the center of rotation. This assumption, while somewhat erroneous, does not affect the general conclusions. For practical purposes, the two forces are equal at all points along the string at any given time, and the magnitude of each force is equal at all points along the string.

In summarizing the conclusions reached by the above example and explanation, consider the following relationship:

$$\text{force} = \frac{\text{mass} \times \text{velocity}^2}{\text{radius}}$$

where velocity represents the linear velocity of the ball. This emphasizes that the centripetal and the centrifugal forces are equal in magnitude and opposite in direction. Each force is directly proportional to the mass of the body and inversely proportional to the radius of rotation. Each force is also proportional to the square of the velocity.

In revolving or rotating bodies, all particles of the matter which are not on the axis of rotation are subjected to the forces just described. The statement is true whether the motion is through a complete circle, or merely around a curve: An aircraft tends to skid when changing course; an automobile tends to take curves on two wheels. The sharper the curve (smaller radius) or the higher the velocity, the greater the tendency to skid.

WAVE PARAMETERS

"Wave parameters" is a general term that applies to all types of waves—water, radio, sound, light, heat. All types of waves exhibit some characteristics in common, that is, they all experience transmission, reflection, refraction, and absorption in very similar manner.

WAVE MOTION

Energy may be transferred progressively from point to point in a medium by a disturbance which may have the form of an elastic deformation, or of a variation of pressure, electric or magnetic intensity, electric potential, or temperature which advances with a finite velocity through the medium. Energy is transferred from one point to another without the passage of matter between the two points, although in some cases particles of matter do move to and fro around their equilibrium position. A single disturbance induced into the medium is called a wave pulse, and a series of waves produced by continuous variations is called a train of waves or wave train.

Transverse Waves

In describing any periodic wave, it is said to be TRANSVERSE if the disturbance takes place at right angles to the direction of propagation. This motion can be easily observed when a hemp line is fastened at one end to a stanchion and its free end moved up and down with a simple periodic motion. The motion of the waves will be along the length of the line but each particle of the line moves at right angles to its length.

Electromagnetic waves do not involve moving particles of matter, but rely on electric and magnetic force fields. The variations of these fields are also at right angles to the direction of wave movement and so are transverse waves. Also, the variations of electric field intensity and those of magnetic field intensity are at right angles to each other as well as to the direction of propagation of the wave. For example, if an electromagnetic wave is moving toward the north and is horizontally polarized, the variations of the electric field intensity are east-west horizontal to the earth's surface, while variations in the magnetic field intensity are vertical. Electromagnetic waves are known as radio waves, heat rays, light rays, etc., depending on their frequency.

Longitudinal Waves

Longitudinal waves are those in which the disturbance takes place in the direction of propagation. The compressional waves that constitute sound such as those set up in air by a vibrating tuning fork are longitudinal waves. When struck, the tuning fork sets up a vibratory motion. As the tine moves in an outward direction, the air immediately in front of the tine is compressed so that its momentary pressure is raised above that at other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction as a compression wave. When the tine returns and moves in the inward direction, the air in front of the tine is rarefied so that its momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is also propagated, but in the form of a rarefaction (expansion) wave, and follows the compression wave through the medium.

The compression and expansion waves are also called longitudinal waves, because the particles of matter which comprise the medium move back and forth longitudinally in the direction of wave travel. Figure 3-7 is a simplified representation of the use of a tuning fork to produce a longitudinal wave. The transverse wave shown below the longitudinal wave is merely a convenient device to indicate the relative density of the particles in the medium, and does not reflect the movement of the particles.

Waves in Water

The motion of the surface of water having waves passing by is a combination of both transverse and longitudinal waves. The particles of water move in circles or in ellipses. This motion can be seen by placing a small cork on the surface of the water and observing it from the side. The cork will be carried upward and in the direction of the wave motion as the crest of the wave approaches; after the crest has passed the cork falls and is then carried backward.

Terms Used in Wave Parameters

VELOCITY.–The velocity of propagation is the rate at which the disturbance transverses the medium, or the velocity with which the crest of the wave moves along. This velocity of the wave must not be confused with the speed of a particle which is always less than the velocity of the wave. The velocity of the wave depends both on the type of wave and the nature of the medium.

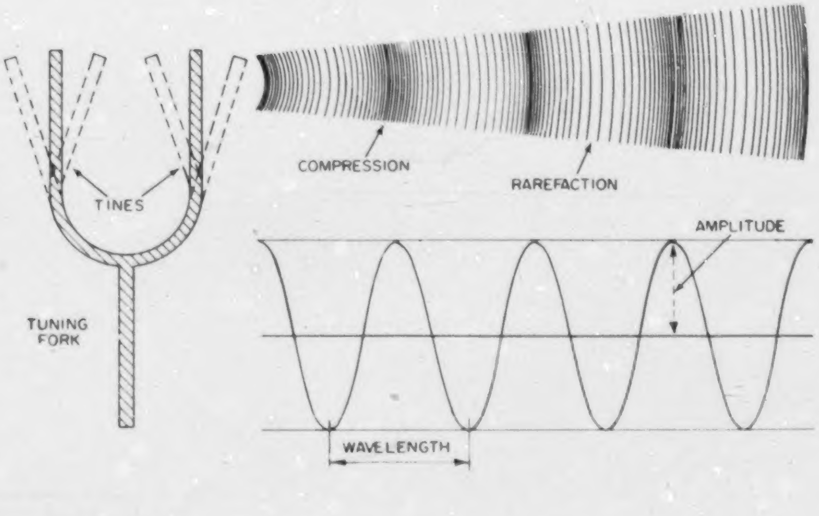


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Figure 3-7.–Compression and expansion wave propagation.

FREQUENCY.–The frequency of any periodic motion is the number of complete variations per unit of time. With waves, the time unit is the second and the frequency unit is hertz (Hz). Hertz is the number of complete cycles per second, and is, therefore, the number of complete waves which pass a given point each second.

PERIOD.–The period of a wave is the time required to complete a full cycle, and so the period and the frequency of a given wave are reciprocals of each other. Thus,

$$\text{period} = \frac{1}{\text{frequency}} \text{ and frequency} = \frac{1}{\text{period}}$$

If a sound wave has a frequency of 400 Hz its period is 1/400 = 0.0025 second. If successive crests of a water wave pass a given point each 5 seconds, the frequency of the wave is 1/5 = 0.2 Hz.

WAVELENGTH.–Wavelength, denoted by the symbol λ (Greek lambda), is the distance, along the direction of propagation of the wave, between two successive points in the medium that are at precisely the same state of disturbance. In a water wave, this is the distance between two adjacent crests. Wavelength is dependent upon both the frequency of the wave and the velocity upon both the frequency of the wave and the velocity of propagation of the wave in a given medium. In compatible units of measure,

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}.$$

Compatible units means that if frequency is waves per second–e.g. hertz–then velocity must be in distance units per second–e.g., feet per second or meters per second. Also, if velocity is given in feet per second, wavelength will be in feet; if velocity is given in meters per second, wavelength will be in meters.

Standing Waves

Standing waves may be produced by two wave trains of the same type and of equal frequency traveling in opposite directions in the same medium, whether the medium be solid, liquid, or gas. Figure 3-8 illustrates the formation of a standing wave represented by the solid curved line. The points "A" and "N" along the horizontal axis of the graphs are fixed points within the medium and are stationary or "standing." Points "N" are the locations within the minimum where the amplitude of the standing wave is always medium and are called nodes. Successive nodes are one-half wavelength apart. Halfway between the nodes are the antinodes (or loops) represented by points "A" on the graph, and are the locations where the standing wave reaches its maximum amplitude (one-quarter wavelength from a node). The dotted curved line represents a wave train traveling from left to right and the dashed curved line represents an equal wave train traveling from right to left, as they would appear if each were the only wave within the medium. However, as they meet they combine with each other, forming the resultant standing wave as shown by the solid curved line, and so cease to exist in their original form.

In the top drawing the crests of the two identical component waves are approaching each other, and in a moment will coincide at points "A". At this time, the standing wave will increase to a maximum amplitude equal to the sum of the two components.

After another interval of time, the crests of the component waves pass each other as shown in the lower drawing, and the standing wave decreases until it becomes zero at the time the two component waves exactly neutralize each other. After this, the standing wave will increase in amplitude in the opposite direction from that in the drawings. However, it may be seen that the points of maximum variation of the standing wave are not moving; also, that at points "N" the standing wave is always at zero, because for any position of the two component waves their magnitudes are the same and their deviations are opposite.

Although the drawing appears similar to transverse waves, the lines may also represent the magnitude and direction of any deviation within the medium caused by the waves.

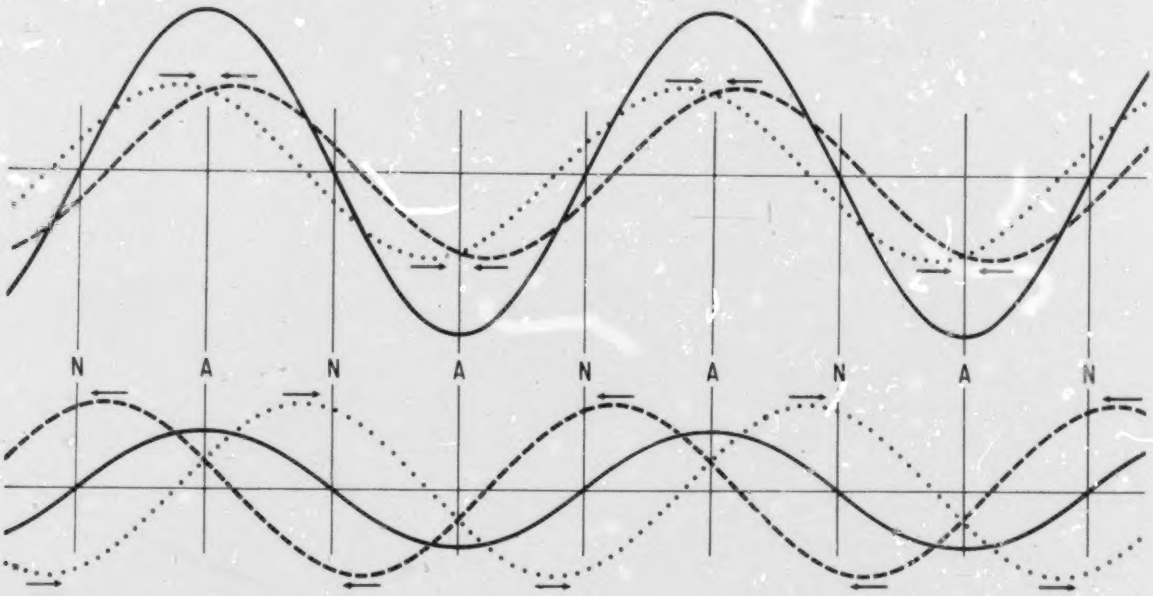

Figure 3-8.–Formation of a standing wave.

REFLECTION

Lines drawn from the source of waves indicating the path along which the waves travel are called RAYS. These lines are frequently used in illustrations as a convenient method of denoting wave propagation. When several rays are drawn from a nearby source they may be shown diverging from the source, but rays drawn from a distant source are usually shown as being more nearly parallel.

A WAVEFRONT is a surface on which the phase of the wave has the same value at all points at a given instant. Wavefronts near the source are sharply curved, but as the distance from the source increases they become more nearly flat.

Within a uniform medium, a ray travels in a straight line. Only at the boundary of two media, or in an area where the velocity of propagation of the wave within the medium changes, do the rays change their direction.

When an advancing wavefront encounters a medium of different characteristics, some of its energy is reflected back into the initial medium, and some may be transmitted into the second medium where it may continue at a different velocity or may be absorbed by the medium. In some cases all three processes (reflection, absorption, and transmission) may occur in some degree.

REFLECTED waves are simply those waves that are neither transmitted nor absorbed, but are thrown back from the surface of the medium they encounter. If a ray is directed against a reflecting surface, the ray striking the surface is called the INCIDENT ray, and the one that bounces back is the REFLECTED ray. An imaginary line perpendicular to the reflecting surface at the point of impact of the incident ray is called the NORMAL. The angle between the incident ray and the normal is called the ANGLE OF INCIDENCE, the angle between the reflected ray and the normal is the ANGLE OF

REFLECTION. These terms are illustrated in figure 3-9.

If the surface of the medium contacted by the incident ray is smooth and polished (as a mirror), each reflected ray will be thrown back at the same angle as the incident ray. The path of the ray reflected from the surface forms an angle exactly equal to the one formed by its path in reaching the medium. This conforms to the law of reflection which states: The angle of incidence is equal to the angle of reflection.

The amount of incident wave energy which is reflected from a surface depends upon the nature of the surface and upon the angle at which the wave strikes the surface. The amount of wave energy reflected increases as the angle of incidence increases, being greatest when the ray is nearly parallel to the surface. When the incident ray is perpendicular to the surface, more of the wave energy is transmitted into the substance and less is reflected. At any incident angle, a mirror reflects almost all of the wave energy, and a dull black surface reflects very little.

Waves which are reflected directly back toward the source cause the standing waves discussed earlier in this chapter.

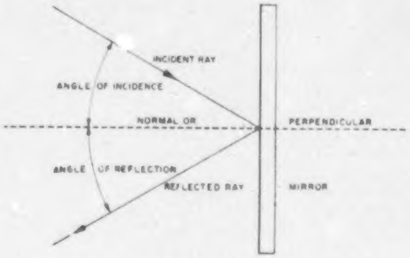

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Figure 3-9.—Terms used to describe the reflection of waves.

REFRACTION

When a ray (or wave) passes from one medium into a medium having a different velocity of propagation for the wave, if the ray is not perpendicular to the boundary between the two media, a change of direction of the wave, or a bending of the ray called REFRACTION, will occur. As in the discussion of reflection, the ray striking the boundary is called the incident ray, and the imaginary line perpendicular to the boundary is called the normal. The angle between the normal and the path of the ray through the second medium is the angle of refraction.

A light ray is shown from points A to B in figure 3-10 and is labeled INCIDENT RAY as it approaches the boundary between the air and the top of the glass plate. Here it bends toward the normal and takes the path B-C through the glass and becomes both the refracted ray from the top surface and the incident ray to the lower surface.

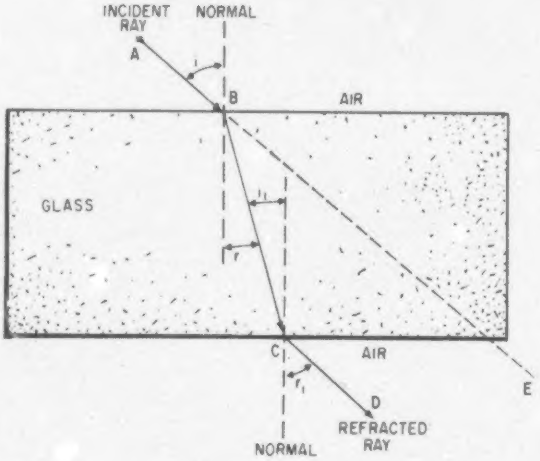

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Figure 3-10.—Refraction of a wave.

The angle formed by the ray and the normal to the lower surface is the second angle of incidence. As the ray passes from the glass to the air it is again refracted, this time away from the normal, and takes the path C-D.

Refraction always follows a general rule—when a ray passes from one medium to another having a lower velocity of propagation for the waves, refraction is toward the normal so the angle of refraction is smaller than the angle of incidence; when passing into a medium having higher velocity of propagation for the waves, refraction is away from the normal so the angle of refraction is larger than the angle of incidence. The angle of refraction is found by experiment to depend on two factors: (1) the angle of incidence, and (2) the index of refraction, which is the ratio of the velocities of the waves within the two media. The greater the angle of incidence, the greater the bending; also, the greater the difference between the velocities of propagation in the two media, the greater the bending.

When the two surfaces of the glass are parallel, the ray leaving the glass will be parallel to the ray entering the glass. The distance between these two paths (between lines A-E and C-D in fig. 3-10) is called lateral displacement. Lateral displacement is zero when the incident ray is directed along the normal, and increases as the angle of incidence increases. Lateral displacement is greater in thicker glass than in thin.

A boundary between two media does not always have a sharp point of transition such as from the surface of glass to air. Air layers above the earth's surface having different temperatures may cause refraction of sound waves, as do thermal layers in the ocean. Variations in the ionosphere cause refraction of radio waves and light rays.

As stated before, when a wave encounters a medium having a higher velocity of propagation, refraction is away from the normal with the angle of refraction being larger than the angle of incidence. When the angle of incidence is increased to the angle at which the refracted wave is 90° to the normal (parallel with the boundary), this angle of incidence is called the critical angle of refraction. Any angle of incidence larger than this will result in total reflection of the incident wave, rather than refraction. The size of the critical angle of refraction is dependent upon the index of refraction of the two media—the larger the index of refraction, the smaller the critical angle of refraction.

DIFFRACTION

Diffraction is the bending of the path of waves when the wavefront is limited by an obstruction. This is very easy to observe in water waves. Generally, the lower frequency waves will diffract more than those at higher frequency. In sound waves, this may be observed by listening to music from an outdoor band and then stepping behind a solid obstruction such as a brick wall. The high notes, having less diffraction, will seem to be reduced in loudness much more than the low notes. Broadcast band radio waves often travel over to the opposite side of a mountain from their source due to diffraction, while higher frequency T.V. signals from the same city might not be detected on the opposite side of this mountain.

DOPPLER EFFECT

When there is relative motion between the source of a wave and a detector of that wave, the apparent frequency at the detector position differs from the frequency at the source. If the distance between the source and the detector is decreasing, more wavefronts are encountered per second than when the distance is constant. This results in an apparent increase in frequency. Conversely, if the separation is increasing, fewer waves are encountered, with an apparent decrease in frequency.

The pitch of the whistle on a fast-moving train sounds higher as the train is approaching than when the train is departing. Though the whistle is generating sound waves of constant frequency, and though they travel through the air at the same velocity in all directions, the distance between the approaching train and the listener is decreasing, so each wave has less distance to travel to reach the observer than the wave preceding it. Thus the waves arrive with less intervals of time between them.

These apparent changes in frequency are called the Doppler effect, and affect the operation of equipment used to detect and measure wave energy. The amount of change in the apparent frequency varies directly with the relative velocities of the source and detector and inversely with the velocity of propagation of the wave within the medium. The Doppler effect is important in dealing with sound wave propagation as applicable to sonar equipment operation, and in dealing with electromagnetic wave propagation as applicable to radar search, target detection, fire control, navigation, etc.

HEAT

Heat represents a form of energy; therefore, it must be readily exchangeable with, or convertible into, other forms of energy. When a piece of lead is struck a sharp blow with a hammer, part of the kinetic energy of the hammer is converted into heat. In the core of a transformer, electrical and magnetic energy are exchanged; but due to hysteresis and eddy currents, some of the energy is lost as heat. These are some examples of the unwanted conversions, but there are many instances when the production of heat is desirable. Many devices are used almost exclusively to produce heat.

Regardless of how or why it is produced, heat possesses certain characteristics which make it important to the technician. A knowledge of the nature and behavior of heat may prove helpful in understanding the operation of some types of electronics equipment or in determining the cause of nonoperation or faulty operation of others.

NATURE OF HEAT

There are several theories regarding the nature of heat, none of which satisfactorily explain all the characteristics and properties exhibited by heat. The two theories most commonly included in discussions regarding the nature of heat are the kinetic theory and the radiant energy theory.

In the kinetic theory, it is assumed that the quantity of heat contained by a body is represented by the total kinetic energy possessed by the molecules of the body.

The radiation theory treats radio waves, heat, and light as the same general form of energy, differing primarily in frequency. Heat is considered as a form of electromagnetic energy involving a specific band of frequencies falling between the radio spectrum and light.

A common method used to produce heat energy is the burning process. Burning is a chemical process in which the fuel unites with oxygen, and a flame is usually produced. The amount of heat liberated per unit mass or per unit volume during complete burning is known as the heat of combustion of a substance. By experiment, scientists have found that each fuel produces a given amount of heat per unit quantity burned.

TRANSFER OF HEAT

There are three methods of heat transfer—conduction, convection, and radiation. In addition to these, a phenomenon called absorption is related to the radiation method.

Conduction

The metal handle of a hot pot may burn the hand; a plastic or wooden handle, however, remains relatively cool even though it is in direct contact with the pot. This phenomenon is due to a property of matter known as thermal conductivity. All materials conduct heat—some very readily, some to an almost negligible extent. When heat is applied to a body, the molecules at the point of application become violently agitated, strike the molecules next to them, and cause increased agitation. The process continues until the heat energy is distributed evenly throughout the material. Aluminum and copper are used for cooking pots because they conduct heat very readily to the food being cooked. Wood and plastic are used as handles because they are very poor conductors of heat. As a general rule metals are the best conductors of heat, although some metals are considerably better than others.

Among solids, there is an extreme range of thermal conductivity. In the original example, the metal handle transmits heat from the pot to the hand, with the possibility of burns. The wooden or plastic handle does not conduct heat very well, so the hand is given some protection. Materials that are extremely poor conductors are called "insulators" and are used to reduce heat transfer. Some examples are the wood handle of soldering irons, the finely spun glass or rock wool insulation in houses, or the asbestos tape or ribbon wrapping used on steam pipes.

Liquids are generally poorer conductors than metals. In figure 3-11, note that the ice in the bottom of the test tube has not yet melted, although the water at the top is boiling. Water is such a poor conductor that the rate of heating of the water at the top of the tube is not sufficient to cause rapid melting of the ice at the bottom.

Since thermal conduction is a process by which molecular energy is passed on by actual contact, gases are generally even poorer conductors than liquids because the molecules are farther apart and molecular contact is not so pronounced. A double-pane window with an airspace between the panes is a fair insulator.

Convection

Convection is the process in which heat is transferred by movement of a hot fluid. For example, an electron tube gets hotter and hotter until the air surrounding it begins to move. The motion of the air is upward because heated air expands in volume and is forced upward by the denser cool air surrounding it. The upward motion of the heated air carries the heat away from the hot tube by convection. Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot vacuum tube can also be increased by providing copper fins to conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown.

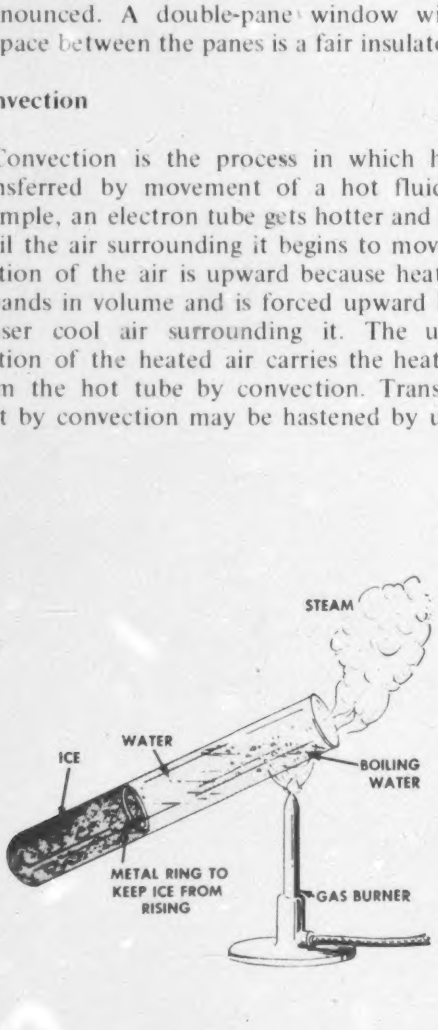


Figure 3-11.—Water is a poor conductor of heat.

A convection process may take place in a liquid as well as in a gas. One example is a transformer in an oil bath. The hot oil is less dense (has less weight per unit volume) and rises, while the cool oil falls, is heated, and rises in turn.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps may be used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations electric fans and blowers are used to aid convection.

Radiation

Conduction and convection cannot wholly account for some of the phenomena that are associated with heat transfer. For example, heating through convection cannot occur in front of an open fire because the air currents are moving toward the fire. It cannot occur through conduction because the conductivity of the air is very low, and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, heat must travel across space by some means other than conduction and convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through molecular contact within some medium, heat from the sun must reach the earth by some other method. (Outer space is an almost perfect vacuum.) Radiation is the name given to this third method by which heat travels from one place to another.

The term radiation refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. It is in the form of electromagnetic waves and is identical in nature with light waves, radio waves, and X-rays, except for a difference in wavelength. Sunlight is a form of radiant heat energy which travels great distances through cold, empty space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The net result is that the motion of the molecules in the body is increased, as indicated by an increase in the temperature of the body.

The differences in conduction, convection, and radiation are as follows:

1. Although conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light.
2. Radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass.
3. Although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

Absorption

The sun, a fire, and an electric light bulb all radiate energy, but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies which do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. This is the reason white clothing is worn in the summer. A practical example of the control of heat is the Thermos bottle. The flask itself is made of two walls of "silvered" glass with a vacuum between them. The vacuum prevents the loss of heat by conduction and convection and the "silver" coating reduces the loss of heat by radiation.

The silver-colored paint on the "radiators" in heating systems is used only for decoration and decreases the efficiency of heat transfer. The most effective color for heat transfer is dull black; dull black is the ideal absorber and also the best radiator.

TEMPERATURE

If an object is hot to the touch, it is said to have a "high" temperature; if it is cold to the touch, it has a "low" temperature. In other words, temperature is used as a measure of the hotness or coldness of an object being described. However, hotness and coldness are only relative. For example, on a cold day, metals seem colder to the touch than nonmetals because they conduct heat away from the body more rapidly. Also, upon leaving a warm room the outside air seems cooler than it really is. Going from the outside cold into a warm room, the room seems warmer than it really is. In other words, the temperature a person feels depends upon the state of his body.

Temperature Conversion

There are many systems of temperature measurement; it is frequently necessary to convert from one to the other. The four most common scales in use today are the Fahrenheit (F), Celsius (C), Rankine (R), and Kelvin (K).

FAHRENHEIT SCALE.–The most familiar scale to most Americans is the Fahrenheit scale which was established so that its zero point approximates the temperature produced by mixing equal quantities by weight of snow and common salt.

Under standard atmospheric pressure the boiling point of water is 212 degrees above zero and the freezing point 32 degrees above zero. Each degree represents an equal division, and there are 180 such divisions between freezing and boiling.

CELSIUS SCALE.–This scale, formerly called the Centigrade scale, uses the freezing point and boiling point of water under standard atmospheric pressure as fixed points of 0 and 100, respectively, with 100 equal divisions between. These 100 divisions represent the same difference in temperature as 180 divisions of the Fahrenheit scale. This ratio of 100/180 reduces to 5/9, which means a change of 1°F is equal to a change of 5/9° C. A change of 5° on the Celcius scale, therefore, is equal to a change of 9° on the Fahrenheit scale. Because 0 on the

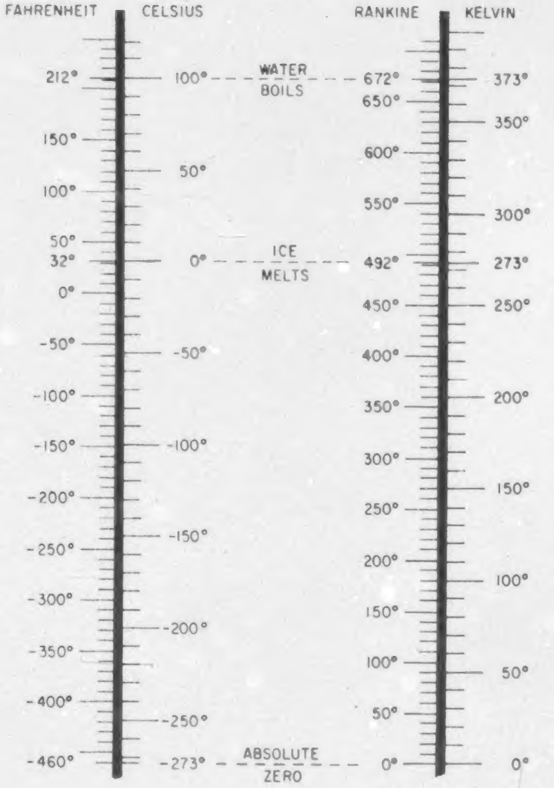
Celsius scale corresponds to 32° on the Fahrenheit scale, a difference in reference points exists between the two ~~scales~~. (See Fig. 3-12.)

To convert from the Fahrenheit scale to the Celsius scale, subtract the 32° difference and multiply the result by 5/9. As an example, convert 68° Fahrenheit to Celsius

$$\frac{5}{9}(68-32)=\frac{5}{9}\times 36=20^\circ \text{ C}$$

To convert Celsius to Fahrenheit, the reverse procedure is necessary. First multiply the reading on the Celsius thermometer by 9/5 and then add 32 to the result—

$$\frac{9}{5}(20)+32=36+32=68^\circ \text{ F}$$



AT. 7

Figure 3-12.—Comparison of the four common temperature scales.

One way to remember when to use 9/5 and when to use 5/9 is to keep in mind that the Fahrenheit scale has smaller divisions than the Celsius scale. In going from Celsius to Fahrenheit, multiply by the ratio that is larger; in going from Fahrenheit to Celsius use the smaller ratio.

Another method of temperature conversion which uses these same ratios is based on the fact that the Fahrenheit and Celsius scales both register the same temperature at −40°; that is, −40° F equals −40° C. This method of conversion, sometimes called the "40 rule," proceeds as follows:

1. Add 40 to the temperature which is to be converted. Do this whether the given temperature is Fahrenheit or Celsius.
2. **Multiply by 9/5 when changing Celsius to Fahrenheit; by 5/9 when changing Fahrenheit to Celsius.**
3. Subtract 40 from the result of step 2. This is the answer.

As an example to show how the 40 rule is used, convert 100° C to the equivalent Fahrenheit temperature:

$$100+40=140$$
$$140\times 9/5=252$$
$$252-40=212$$

Therefore, 100° C = 212° F. Remember that the multiplying ratio for converting F to C is 5/9, rather than 9/5. Also remember to always ADD 40 first, then multiply, then SUBTRACT 40, regardless of the direction of the conversion.

It is important that all technicians be able to read thermometers and to convert from one scale to the other. In some types of electronic equipment, thermometers are provided as a check on operating temperatures. Thermometers are also used to check the temperature of a charging battery.

KELVIN SCALE.—Also known as the absolute scale, the Kelvin scale has as its zero point the temperature which has been indicated by experiments with hydrogen as the point where all molecular motion would cease and no additional heat could be extracted from the substance. Theoretically, this is referred to as absolute zero temperature. This point is −273.16° C, but −273° C is used for most calculations as shown in figure 3-12. The spacing between degrees is the same as for the Celsius scale, and so conversion from the Celsius is made by adding 273 to the Celsius temperature.

RANKINE SCALE.–This scale has the same spacing between degrees as the Fahrenheit scale, but has its zero corresponding to 0° K (absolute zero). This is calculated to be −459.69° F, but −460° F is usually used. To convert Fahrenheit to Rankine, add 460 to the Fahrenheit temperature.

Since Rankine and Kelvin both have the same zero point, conversion between the two scales requires no addition or subtraction. Rankine temperature is equal to 9/5 times Kelvin temperature and Kelvin temperature is equal to 5/9 Rankine temperature.

Formulas may be derived for converting between Fahrenheit and Kelvin and between Celsius and Rankine from the information already given, and since they are less frequently needed are not included here.

Thermal Expansion

Nearly all substances expand or increase in size when their temperature increases. Railroad tracks are laid with small gaps between the sections to prevent buckling when the temperature increases in summer. Concrete pavement has strips of soft material inserted at intervals to prevent buckling when the sun heats the roadway. A steel building or bridge is put together with red-hot rivets so that when the rivets cool they will shrink and the separate pieces will be pulled together very tightly.

As a substance is expanded by heat, the weight per unit volume decreases. This is because the weight of the substance remains the same while the volume is increased by the application of heat. Thus the density decreases with an increase in temperature.

Experiments show that for a given change in temperature, the change in length or volume is different for each substance. For example, a given change in temperature causes a piece of copper to expand nearly twice as much as a piece of glass of the same size and shape. For this reason, the connecting wires into an electronic tube cannot be made of copper but must be made of a metal that expands at the same rate as glass. If the metal does not expand at the same rate as the glass, the vacuum in the tube is broken by air leaking past the wires in the glass stem. The metal usually used for this purpose is an alloy called kovar.

The amount that a unit length of any substance expands for a 1° rise in temperature is known as the coefficient of linear expansion for that substance. The temperature scale used must be specified.

COEFFICIENTS OF EXPANSION.–To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it–its length, the rise in temperature to which it is subjected, and its rate or coefficient of expansion. The amount of expansion is expressed by the following equation:

$$\text{expansion} = \text{coefficient} \times \text{length} \times \text{rise in temperature}$$

or

$$e = kl(t_2 - t_1)$$

In this equation, the letter k represents the coefficient of expansion for the particular substance. In some instances, the Greek letter α is used to indicate the coefficient of linear expansion.

PROBLEM: If a steel rod measures exactly 9 feet at 21° C, what is its length at 55° C? (The coefficient of linear expansion for steel is 11×10^{-6}.) If the equation $e = kl\ (t_2 - t_1)$ is used, then

$$e = (11 \times 10^{-6}) \times 9 \times (55 - 21)$$

$$e = 0.000011 \times 9 \times 34$$

$$e = 0.003366$$

This amount, when added to the original length of the rod, makes the rod 9.003366 feet long.

(Since the temperature has increased, the rod is longer by the amount of e. If the temperature had been lowered, the rod would have become shorter by a corresponding amount.)

The increase in the length of the rod is relatively small; but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing ships, buildings, and all forms of machinery.

Table 3-5 is a list of the coefficients of approximate linear expansion of some substances per degree C.

A practical application for the differences in the coefficients of linear expansion is the thermostat. This instrument comprises two strips of dissimilar metal fastened together. When the temperature changes, a bending takes place due to the unequal expansion of the metals (fig. 3-13). Thermostats are used in overload relays for motors, in temperature sensitive switches, and in electric ovens. (See fig. 3-14.)

The coefficient of surface or area expansion is approximately twice the coefficient of linear expansion. The coefficient of volume expansion is approximately three times the coefficient of linear expansion. It is interesting to note that in a plate containing a hole, the area of the hole expands at the same rate as the surrounding material. In the case of a volume enclosed by a thin solid wall, the volume expands at the same rate as would a solid body of the material of which the walls are made.

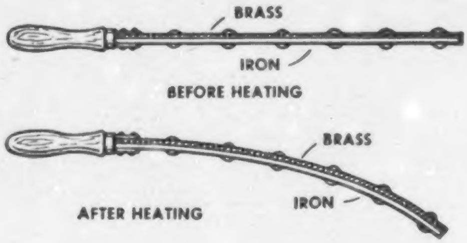


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Figure 3-13.–Compound bar.

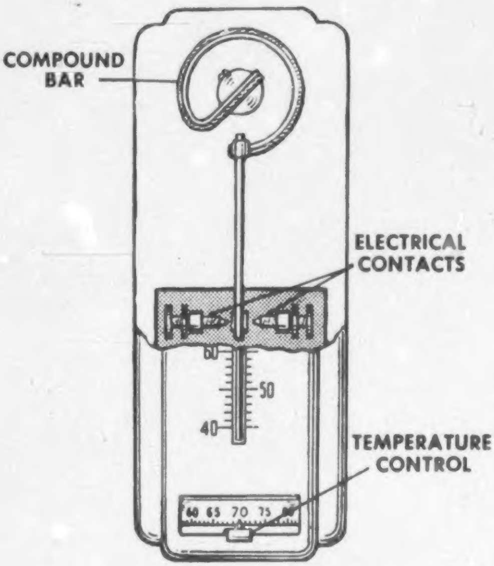

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Figure 3-14.–Thermostat.

Table 3-5.–Expansion coefficients.

Substance	Coefficient of linear expansion
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Glass	4 to 9×10^{-6}
Kovar	4 to 9×10^{-6}
Lead	28×10^{-6}
Iron, Steel	11×10^{-6}
Quartz	0.4×10^{-6}
Zinc	26×10^{-6}

Thermometers

The measurement of temperature is known as THERMOMETRY. Many modern thermometers use liquids in sealed containers. Water was the first liquid used, but because it freezes at 0° C it could not measure temperatures below that point. After much experimentation, scientists decided that the best liquids to use in the construction of thermometers are alcohol and mercury because of the low freezing points of these liquids.

LIQUID THERMOMETERS. The construction of the common laboratory thermometer gives some idea as to the meaning of a change of 1° in temperature. A bulb is blown at one end of a piece of glass tubing of small bore. The tube and bulb are then filled with the liquid to be used. The temperature of both the liquid and the tube during this process are kept at a point higher than the thermometer will reach in normal usage. The glass tube is then sealed and the thermometer is allowed to cool. During the cooling process, the liquid falls away from the top of the tube and creates a vacuum within the thermometer.

For marking, the thermometer is placed in melting ice. The height of the liquid column is marked as the 0° C point. Next, the thermometer is placed in steam at a pressure of 76 centimeters of mercury and a mark is made at that point to which the liquid inside rises. That is the boiling point or the 100° C, mark. The space between these two marks is then divided into 100 equal parts. These spacings are known as DEGREES. It is this type of thermometer that is used almost exclusively in laboratory work and in testing electrical equipment. It is the Celsius thermometer mentioned earlier.

SOLID THERMOMETERS. Because the range of all liquid thermometers is extremely limited, other methods of thermometry are necessary. Most liquids freeze at temperatures between 0° and −200° Celsius. At the upper end of the temperature range where high heat levels are encountered, the use of liquid thermometers is limited by the high vapor pressures of those liquids. Among the most widely used types of thermometers other than the standard liquid thermometers are the resistance thermometer, and the thermocouple.

The RESISTANCE THERMOMETER makes use of the fact that the electrical resistance of metals changes as the temperature changes. This type thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The THERMOCOUPLE shown in figure 3-15 is essentially an electric circuit. Its operation is based on the principle that when two unlike metals are joined and the junction is at a different temperature from the remainder of the circuit, an electromotive force is produced. This electromotive force can be measured with great accuracy by a galvanometer. Thermocouples can be located wherever measurement of the temperature is important, and wires run to a galvanometer located at any convenient point. By means of a rotary selector switch, one galvanometer can read the temperatures of thermocouples at any of a number of widely separated points.

The principle of the compound bar (figure 3-13) is also used in thermometers. The bar may be in the shape of a spiral, or perhaps a helix, so that within a given enclosure a greater length of

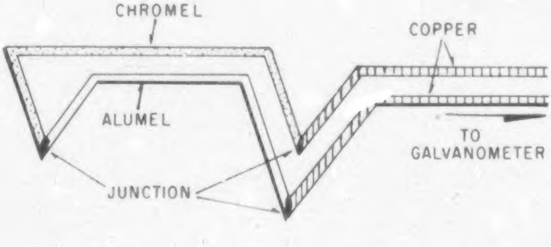

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Figure 3-15.—Thermocouple.

the compound bar may be used, thereby increasing the movement of the free end per degree of temperature change. Also, the indicating pointer may be joined to the moving end of the compound bar by means of distance multiplying linkage to make the thermometer easier to read. Often this linkage is arranged to give circular movement to the pointer.

MEASUREMENT OF HEAT

A unit of heat must be defined as the heat necessary to produce some agreed-on standard of change. There are three such units in common use.

1. One British thermal unit (Btu) is the quantity of heat necessary to raise the temperature of 1 pound of water 1° F.

2. One gram-calorie (small calorie) is the quantity of heat necessary to raise 1 gram of water 1° C.

3. One kilogram-calorie (large calorie) is the quantity of heat necessary to raise 1 kilogram of water 1° C. (One kilogram-calorie equals 1,000 gram-calories.) The gram-calorie or small calorie is much more widely used than the kilogram-calorie or large calorie. The large calorie is used in relation to food energy and for measuring comparatively large amounts of heat. Throughout this discussion, unless otherwise stated, the term calorie means gram-calorie. For purposes of conversion, one Btu equals 252 gram-calories or 0.252 kilogram-calories.

The terms quantity of heat and temperature are commonly misused. The distinction between them should be understood clearly. For example, suppose that two identical pans, containing different amounts of water of the same temperature, are placed over identical gas burner flames for the same length of time. At the end of that time, the smaller amount of water will have reached a higher temperature. Equal amounts of heat have been supplied, but the increases in temperatures are not equal. As another example, suppose that the water in both pans is at the same temperature, say 80° F, and both are to be heated to the boiling point. It is obvious that more heat must be supplied to the larger amount of water. The temperature rises are the same for both pans, but the quantities of heat necessary are different.

Mechanical Equivalent

Mechanical energy is usually expressed in ergs, joules, or foot-pounds. Energy in the form of heat is expressed in calories or in Btu. In a precise experiment in which electric energy is converted into heat in a resistance wire immersed in water, the results show that 4.186 joules equals 1 gram-calorie, or that 778 foot-pounds equals 1 Btu. The following equation is used when converting from the English system to the metric system:

$$1 \text{ Btu} = 252 \text{ calories}$$

Specific Heat

One important way in which substances differ from one another is that they require different quantities of heat to produce the same temperature change in a given mass of substance. The thermal capacity of a substance is the calories of heat needed, per gram mass, to increase the temperature 1°C. The specific heat of a substance is the ratio of its thermal capacity to the thermal capacity of water at 15° C. **Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the** English and the metric systems.

Water has a high thermal heat capacity. Large bodies of water on the earth keep the air and the surface of the earth at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature of the air falls below that of such bodies of water, they give off large quantities of heat to the air. This process keeps the atmospheric temperature at the surface of the earth from changing very rapidly.

Table 3-6 gives the specific heats of several common substances listed in descending order. To find the heat required to raise the temperature of a substance, multiply its mass by the rise in temperature times its specific heat.

Example: It takes 1,000 Btu to raise the temperature of 100 pounds of water 10° F, but only 31 Btu to raise 100 pounds of lead 10° F.

CHANGE OF STATE

A thermometer placed in melting snow behaves in a strange manner. The temperature of

Table 3-6.—Specific heats of some common substances.

Hydrogen (at constant pressure)	3.409
Water at 4°C	1.0049
Water at 15°C	1.0000
Water at 30°C	0.9971
Ice at 0°C	0.502
Steam at 100°C	0.421
Air (at constant pressure)	0.237
Aluminum	0.217
Glass	0.160
Iron	0.114
Copper	0.093
Brass, zinc	0.092
Silver	0.057
Tin	0.056
Mercury	0.033
Gold, lead	0.031

the snow rises slowly until it reaches 0° C. Provided that the mixture is stirred constantly, it remains at that point until all the snow has changed to water; when all the snow has melted, the temperature again begins to rise. A definite amount of heat is required to change the snow to water at the same temperature. This heat is required to change the water from crystal form to liquid form.

Heat of Fusion

Eighty gram-calories of heat are required to change 1 gram of ice at 0° C to water at 0° C. In English units, the heat required to change 1 pound of ice at 32° F to water at 32° F is 144 Btu. These values (80 gram-calories and 144 Btu) are called the HEAT OF FUSION of water. The heat used while the ice is melting represents the work done to produce the change of state. Since 80 calories are required to change a gram of ice to water at 0° C, when a gram of water is frozen it gives up 80 calories.

Many substances behave very much like water. At a given pressure, they have a definite heat of fusion and an exact melting point. There are many materials, however, which do not change from a liquid to a solid state at one temperature. Molasses, for example, gets thicker and thicker as the temperature decreases; but there is no exact temperature at which the change of state occurs. Wax, celluloid, and glass are other substances which do not change from a liquid to a solid state at any particular temperature. In fact, measurements of the glass thickness at the bottom of windows in ancient cathedrals tend to indicate that the glass is still flowing at an extremely slow rate. Most types of solder used in electronics maintenance also tend to become mushy before melting.

Heat of Vaporization

Damp clothing dries more rapidly under a hot flatiron than under a cold one. A pool of water evaporates more rapidly in the sun than in the shade. Thus, it may be concluded that heat has something to do with evaporation. The process of changing a liquid to a vapor is similar to that which occurs when a solid melts.

If a given quantity of water is heated until it evaporates—that is, changes to a gas (vapor)—a much greater amount of heat is used than that which is necessary to raise the same amount of water to the boiling point. For example, 540 calories are required to change 1 gram of water to vapor at a temperature of 100° C. It takes 972 Btu to change 1 pound of water at 212° F to water vapor (steam) at 212° F. The amount of heat necessary for this change is called the HEAT OF VAPORIZATION of water. Over five times as much heat is required to change a given amount of water to vapor than to raise the same amount of water from the freezing to the boiling point.

BOILING.—When water is heated, some vapor forms before the boiling point is reached. The change from water to vapor occurs as follows: As the water molecules take up more and more energy from the heating source, their kinetic energy increases. The motion resulting from the high kinetic energy of the water molecules causes a pressure which is called the vapor pressure. As the velocity of the molecules increases, the vapor pressure increases. At sea level, atmospheric pressure is normally 29.92 inches of mercury. The boiling point of a liquid is that temperature at which the vapor pressure equals the external or atmospheric pressure. At normal atmospheric pressure at sea level, the boiling point of water is 100° C or 212° F.

While the water is below the boiling point, a number of molecules acquire enough kinetic energy to break away from the liquid state into a vapor. For this reason some evaporation slowly takes place below the boiling point. At the boiling point or above, large numbers of molecules have enough energy to change from liquid to vapor and the evaporation takes place much more rapidly.

If the molecules of water are changing to water vapor in an open space, the air currents carry them away quickly. In a closed container, they rapidly become crowded and some of them bounce back into the liquid as a result of collisions. When as many molecules are returning to the liquid state as are leaving it, the vapor is said to be saturated. Experiments have shown that saturated vapor in a closed container exerts a pressure and has a given density at every temperature.

LIGHT

The exact nature of light is not fully understood, although men have been studying the subject for many centuries. Some experiments seem to show that light is composed of tiny particles, and some indicate that it is made up of waves.

First one theory and then the other attracted the approval and acceptance of the physicists. Today there are scientific phenomena which can be explained only by the wave theory and another large group of occurrences which can be made clear by the particle or corpuscular theory. Physicists, constantly searching for some new discovery which would bring these contradictory theories into agreement, gradually have come to accept a theory concerning light which is a combination of these two views.

According to the view now generally accepted, light is a form of electromagnetic radiation; that is, light and similar forms of radiation are made up of moving electric and magnetic forces.

CHARACTERISTICS

When light waves, which travel in straight lines, encounter any substance, they are transmitted, reflected, or absorbed. Those substances which permit clear vision through them, and which transmit almost all the light falling upon them, are said to be transparent. Those substances which allow the passage of part of the light, but appear clouded and impair vision substantially, are called translucent. Those substances which transmit no light are called opaque.

Objects which are not light sources are visible only because they reflect part of the light reaching them from some luminous source. If light is neither transmitted nor reflected, it is absorbed or taken up by the medium. When light strikes a substance, some absorption and reflection always take place. No substance completely transmits, reflects, or absorbs all the light which reaches its surface.

Luminous Intensity and Intensity of Illumination

Though these two terms may sound like the description of the same property, luminous intensity refers to the total light produced by a source while intensity of illumination describes the amount of light received per unit area at a distance from the source.

CANDLEPOWER.–This unit of luminous intensity was once defined as the light produced by the flame of a certain type of candle, the constituents of which were specified by international agreement. The modern standard candlepower is the amount of light emitted by a 1/60 square centimeter of platinum at its melting point of 1,755° C.

FOOT-CANDLE.–The intensity of illumination of a surface (illuminance) is directly proportional to the luminous intensity of the light source and is inversely proportional to the square of the distance between the light source and the surface. Figure 3-16 is a graphic illustration of the inverse square law of light. If a card is placed 1 foot from a light source, the light striking the card is of a certain intensity. If the card is moved to 2 feet away, the intensity of light decreases with the square of the distance (2 X 2, or 4 times) and is 1/4 as bright. If the card is moved to 3 feet away, the decrease is 3 X 3, or the light is 1/9 as intense. If the card is moved to 4 feet away, the light is 1/16 as intense.

The foot-candle is one unit of measuring this intensity of incident light using the formula:

$$\text{Illumination in foot-candles} = \frac{\text{candlepower of source}}{(\text{distance in feet})^2}.$$

A surface 1 foot from a 1-candlepower source would have an illumination of 1 foot-candle, but if moved to a distance of 4 feet, a 16-candlepower source would be required for the same illumination.

The inverse square law of light holds true for undirected light only; that is, light emissions not controlled by a reflector or lens. For light that is directed, the rate at which its intensity diminishes is dependent upon the rate or divergence of the beam.

LUMEN.—This unit is the amount of light flowing through a solid angle of 1 radian (that is, to a surface area of 1 square foot placed 1 foot from the source) from a standard candle. A light source of 1 candlepower, placed in the center of a sphere which has a radius of 1 foot, will illuminate every point on the surface of the sphere at an intensity of 1 foot-candle. Then every square foot of the surface receives 1 lumen

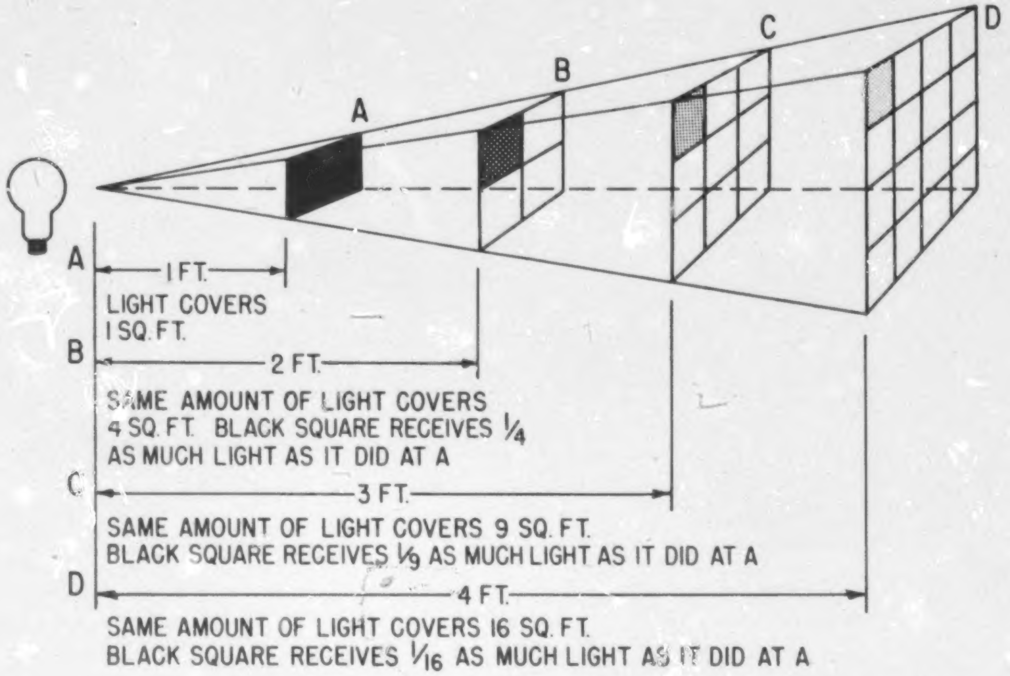

A
B
C
D
A
1 FT.
LIGHT COVERS
1 SQ. FT.
B
2 FT.
SAME AMOUNT OF LIGHT COVERS
4 SQ. FT. BLACK SQUARE RECEIVES 1/4
AS MUCH LIGHT AS IT DID AT A
C
3 FT.
SAME AMOUNT OF LIGHT COVERS 9 SQ. FT.
BLACK SQUARE RECEIVES 1/9 AS MUCH LIGHT AS IT DID AT A
D
4 FT.
SAME AMOUNT OF LIGHT COVERS 16 SQ. FT.
BLACK SQUARE RECEIVES 1/16 AS MUCH LIGHT AS IT DID AT A
PH.22

Figure 3-16.—Inverse square law of light.

of light. The total surface of the sphere is found by the formula $4\pi r^2$, so that when the radius is 1 foot the area is $4 \times 3.1416 \times 1^2 = 12.5664$ square feet. Therefore a source of 1 candlepower emits 12.5664 lumens.

The output of light bulbs may be given either in candlepower or in lumens, but since the light bulb may not distribute the light equally in all directions, the lumen is most frequently used. It is customary for light bulb manufacturers to measure the light output in all directions and specify its total output in lumens. When the total output in lumens is known, the average candlepower, more commonly known as the mean candlepower, is obtained by dividing by 4π (12.5664).

The common gas-filled tungsten filament light bulbs are usually more efficient in the larger sizes. For example, one with an input power of 25 watts produces about 260 lumens (10.4 lumens per watt) while a 200-watt bulb produces 3,640 lumens (18.2 lumens per watt).

LUX.—To express the intensity of illumination given to an object using lumens, it is necessary to give lumens per unit area. The 1 foot-candle is equal to 1 lumen per square foot. One lumen per square meter is the unit lux in the mks system. Since there are 10.764 square feet in a square meter, the foot-candle is 10.764 lux. The lux, then, is the illumination given to a surface 1 meter away from a 1 candlepower source and is sometimes called a meter-candle.

PHOT.—Another unit of illumination, the phot, is equal to 1 lumen per square centimeter. Since 1 square centimeter equals 0.001076 square foot, a foot-candle is equal to 0.001076 phot. The phot, then, is the illumination given to a surface 1 centimeter away from a 1 candlepower source and is sometimes called a centimeter-candle.

LUMINANCE.—Whether a body is self-luminous or just a reflector of the light that falls upon it, luminance (or brightness) refers to the light a surface gives off in the direction of the observer. The LAMBERT is the unit of luminance equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of 1 lumen per square centimeter. For a perfectly reflecting and perfectly diffusing surface, the number of lamberts is equal to the number of phots (incident light).

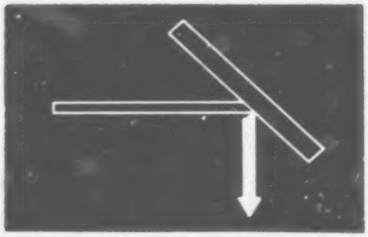
The FOOT-LAMBERT is the unit of luminance of a surface emitting or reflecting 1 lumen per square foot. For a perfectly reflecting and perfectly diffusing surface, the number of foot-lamberts is equal to the number of foot-candles (incident light). One foot-lambert is equal to 0.001076 lambert (1.076 millilambert).

Reflection

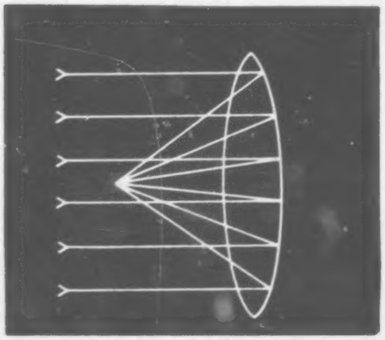
Light waves obey the law of reflection in the same manner as other types of waves. Optical devices incorporated specifically for the purpose of reflecting light are generally classed as mirrors. They may be of a polished opaque surface, or they may be a specially coated glass. In the case of the glass mirror, there is some refraction as well as reflection; however, if the glass is of good quality and not excessively thick, the refraction will cause no trouble. The following discussion is based on the polished surface type mirror.

Several classes of mirrors are illustrated in figure 3-17. All the devices work on the basis of the previously discussed law of reflection, and the applications are only briefly summarized here. Basically, the reflector is used to change the direction of a light beam (A), to focus a beam of light (B), or to intensify the illumination of an area (C).

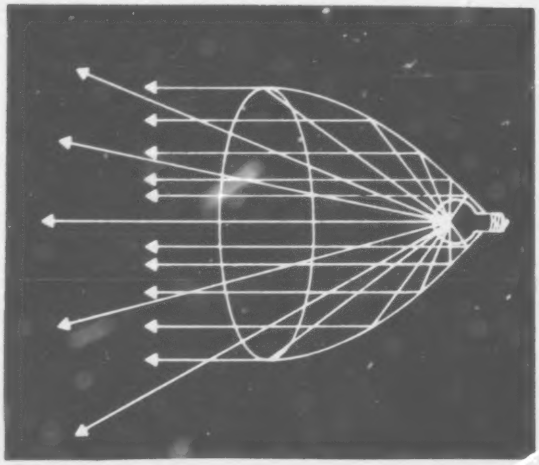
In figure 3-17 (A), the angle of the reflected light may be changed to a greater or lesser degree by merely changing the angle at which the incident light impinges upon the mirror. In figure 3-17 (B), the focusing action of a concave mirror is indicated. The point of focus may be made any convenient distance from the reflector by proper selection of the arc of curvature of the mirror—the sharper the curvature, the shorter the focal length. In figure 3-17 (C), the principle of intensification of illumination for a specific area is illustrated. The flashlight is an example of this application. In the system shown, note that the light source (bulb) is located approximately at the principal focus point, and that all rays reflected from the surface are parallel. Also note that the reflector alone does not concentrate all the rays—some



(A) CHANGING DIRECTION



(B) FOCUSING A BEAM



(C) ILLUMINATING AN AREA

AT.37

Figure 3-17.—Reflectors of light.

are transmitted without being reflected and are not included in the principal beam.

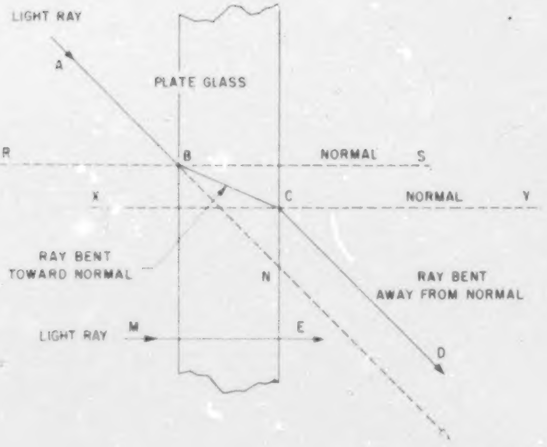
Refraction

As light passes through a transparent substance, it travels in a straight line. However, as it passes into or out of that substance, it is refracted in the same manner as other waves which were discussed earlier. Refraction of light waves results from the fact that light travels at slightly different velocity in different transparent media. In order to simplify the problem of understanding the action of light refraction, and to make it possible to predict the outcome of specific applications, many transparent substances have been tested for refractive effectiveness. **The ratio of the speed of light in air to its** speed in each transparent substance is called the "index of refraction" for that substance. For example, light travels about one and one-half times as fast in air as it does in glass, so the index of refraction of glass is about 1.5. When using the law of refraction in connection with light, a "denser" medium refers to a medium with a higher index of refraction.

Refraction through a piece of plate glass is shown in figure 3-18. The ray of light strikes the glass plate at an oblique angle along path AB. If it were to continue in a straight line, it would emerge from the plate at point N; but in accordance with the law of refraction, it is bent toward the normal, RS, and emerges from the glass at point C. Upon entering the air, the ray does not continue on its path but is bent away from the normal, XY, and along the path CD in the air. If the two surfaces of the glass are parallel, the ray leaving the glass is parallel to the ray entering the glass. The displacement depends upon the thickness of the glass plate, the angle of entry into it, and the index of refraction for the glass.

All rays striking the glass at any angle other than perpendicular are refracted in the same manner. In the case of a perpendicular ray, no refraction takes place, and the ray continues through the glass and into the air in a straight line.

PRISMS. When a ray of light passes through a flat sheet of glass, it emerges parallel to the


LIGHT RAY
A
PLATE GLASS
R
B
NORMAL
S
X
C
NORMAL
Y
RAY BENT TOWARD NORMAL
N
RAY BENT AWAY FROM NORMAL
LIGHT RAY
M
E
D

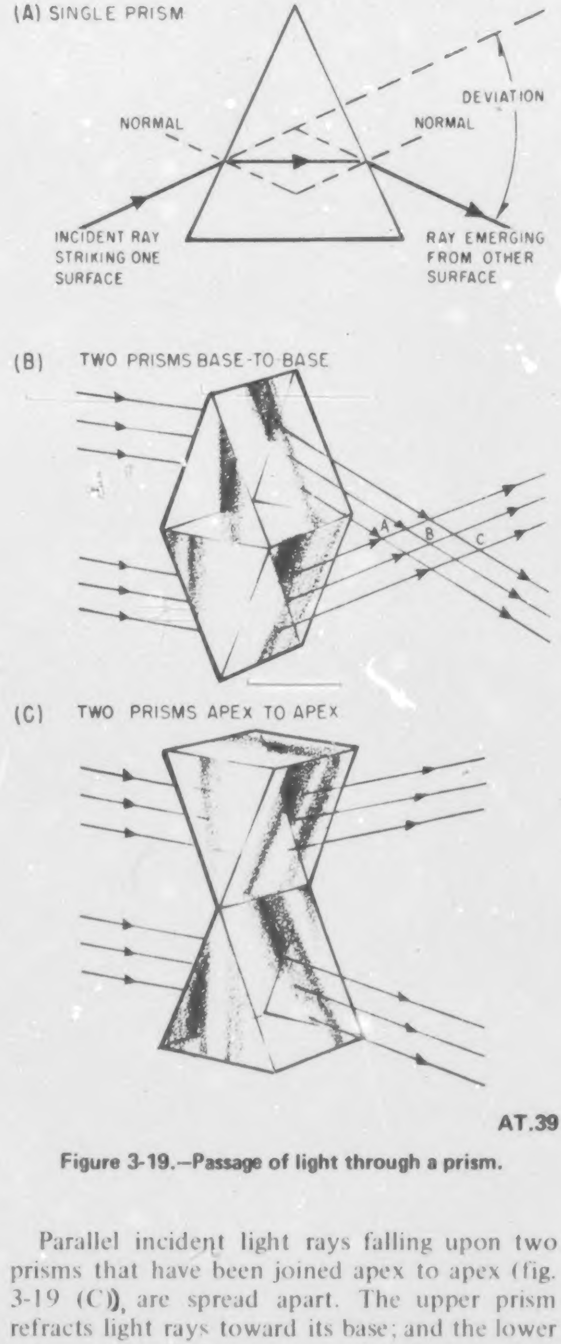
PH.17

Figure 3-18.—The law of refraction.

incident ray. This holds true only when the two surfaces of the glass are parallel. When the two surfaces are not parallel, as in a prism, the ray is refracted differently at each surface of the glass and does not emerge parallel to the incident ray.

Figure 3-19 (A) shows that both refractions are in the same direction and that the ray coming out of the prism is not parallel to the ray going into it. The law of refraction explains what has happened. When the ray entered the prism, it was bent toward the normal; and when it emerged, it was bent away from the normal. Notice that the deviation is the result of the two normals not being parallel.

If two triangular prisms are placed base to base, as in figure 3-19 (B), parallel incident rays passing through them are refracted and caused to intersect. The rays passing through different parts of the prisms, however, do not intersect at the same point. In the case of two prisms there are only four refracting surfaces. The light rays from different points on the same plane are not refracted to a point on the same plane behind the prism. They emerge from the prisms and intersect at different points along an extended common baseline as illustrated by points A, B, and C of figure 3-19 (B).


(A) SINGLE PRISM
NORMAL
NORMAL
DEVIATION
INCIDENT RAY STRIKING ONE SURFACE
RAY EMERGING FROM OTHER SURFACE
(B) TWO PRISMS BASE-TO-BASE
A
B
C
(C) TWO PRISMS APEX TO APEX

AT.39

Figure 3-19.—Passage of light through a prism.

Parallel incident light rays falling upon two prisms that have been joined apex to apex (fig. 3-19 (C)), are spread apart. The upper prism refracts light rays toward its base; and the lower prism refracts light rays toward its base, causing the two sets of rays to diverge.

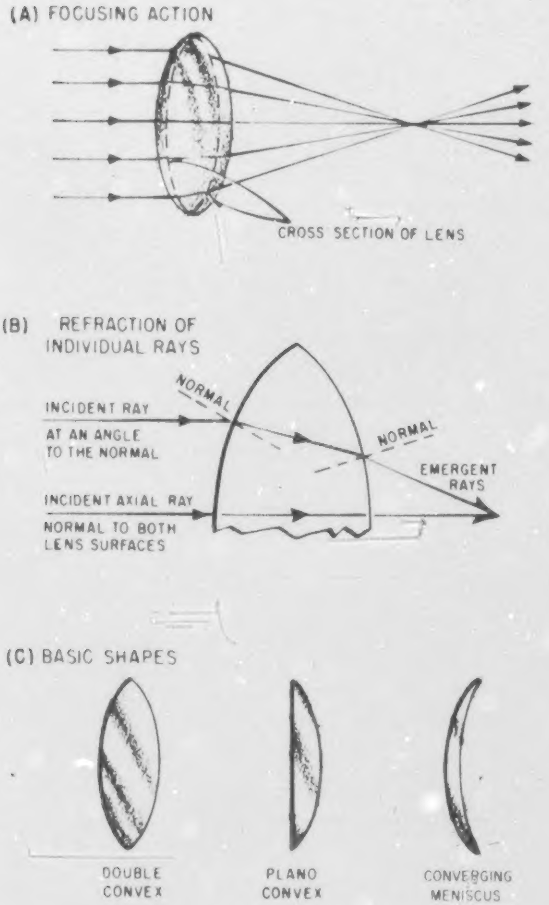


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Figure 3-20.—Positive lenses.

POSITIVE LENSES. A positive (convergent) lens acts like two prisms base to base with their surfaces rounded off into a curve. Rays that strike the upper half of the lens bend downward, and rays that strike the lower half bend upward. A good lens causes all wavelengths within each ray to cross at the same point behind the lens as shown in figure 3-20 (A).

When the incident ray of light enters the denser medium (the lens), it bends toward the normal. When it passes through into the less dense medium (the air), it bends away from the normal. Figure 3-20 (B) illustrates the refraction of only one ray of light, but all rays passing through a positive lens are affected in the same way. All incident light rays either parallel or slightly diverging will converge to a point after passing through a positive lens.

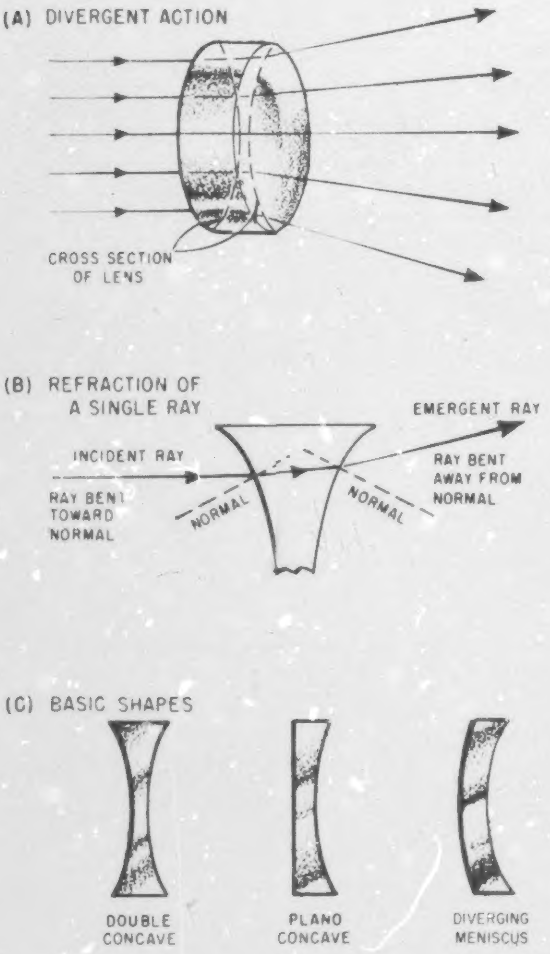
The only ray of light that can pass through a lens without bending is the ray which strikes the first surface of the lens at a right angle, perpendicular or normal to the surface. It passes through that surface without bending and strikes the second surface at the same angle. It leaves the lens without bending. This ray is shown in figure 3-20 (B).

Positive lens and convergent lens are synonymous terms, since either of them may be used to describe the action of a lens which focuses (brings to a point of convergence) all light rays passing through it. All simple positive lenses are easy to identify since they are thicker in the center than at the edges. The three most common types of simple positive lenses are shown in figure 3-20 (C).

NEGATIVE LENSES. Figure 3-19 (C) illustrates the refraction of light rays by two prisms apex to apex. If the prism surfaces are rounded the result is a negative (divergent) lens. A negative lens is called a divergent lens since it does not focus the rays of light passing through it. Light rays passing through a negative lens diverge or spread apart as shown in figure 3-21 (A).

Figure 3-21 (B) applies the law of refraction to one ray of light passing through a negative lens. Just as in a positive lens, a ray of light passing through the center of a negative lens is not affected by refraction and passes through without bending.

Three simple negative lenses are shown in figure 3-21 (C). They are often referred to as concave lenses and are readily identified by their concave surfaces. The simple negative lenses are thicker at the edges than at the center. They are generally used in conjunction with simple positive lenses where their primary use is to assist in the formation of a sharper image by helping to eliminate or subdue various defects present in an uncorrected simple positive lens.



AT. 41

Figure 3-21.—Negative lenses.

FREQUENCIES AND COLOR

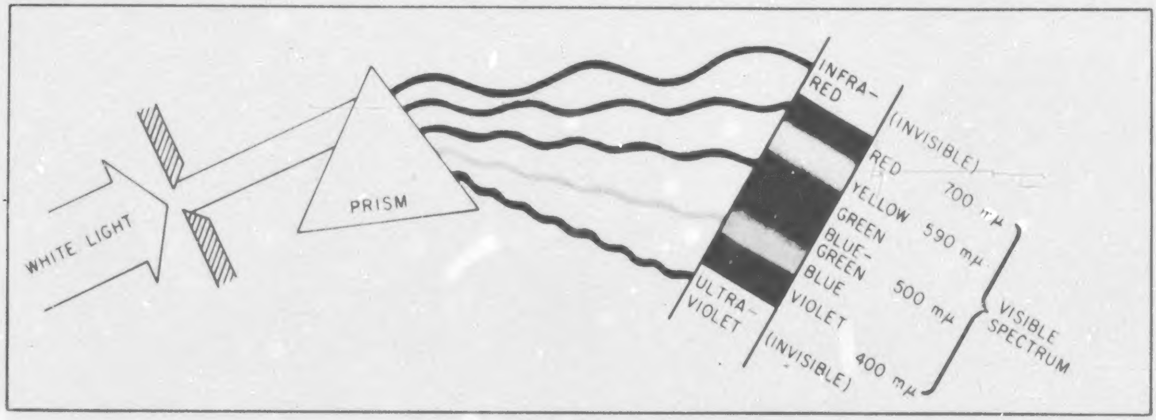
The electromagnetic waves which produce the sensation of light are all very high in frequency, which means that they have very short wavelengths. These wavelengths are measured in millimicrons (millionths of millimeters, or 10^{-9} meters). Figure 3-22 indicates that light with a wavelength of 700 millimicrons is red, and that a light with a wavelength of 500 millimicrons is blue-green. This drawing is subject to erroneous interpretation. In actual fact, the color of light is dependent on its frequency, not its wavelength.

When the wavelength of 700 millimicrons is measured in air, it produces a color known as red, but the same wave measured in another medium has a wavelength other than 700 millimicrons. When red light which has been traveling in air enters glass, it loses speed and its wavelength becomes shorter or compressed, but it continues to be red. This illustrates that the color of light is dependent upon frequency and not on wavelength. The color scale in figure 3-22 is based on the wavelengths in air.

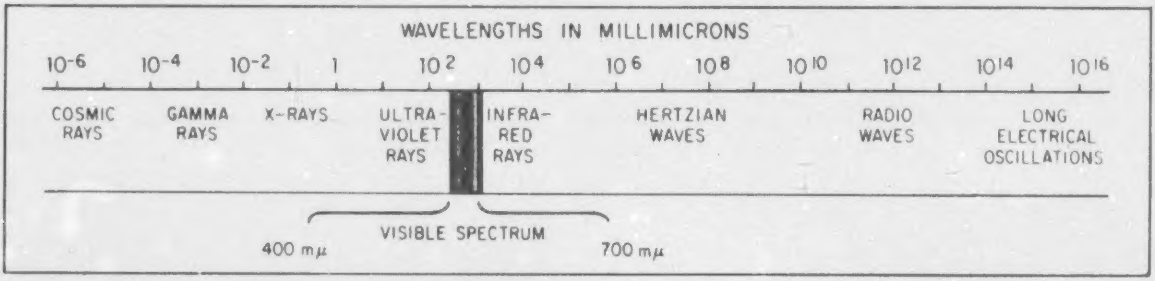
All color-component wavelengths of the visible spectrum are present in equal amounts in white light. Variations in composition of the component wavelengths result in other characteristic colors.

Experiment has shown that when a beam of white light is passed through a prism, as shown in figure 3-22, it is refracted and dispersed into its component wavelengths. Each of these wavelengths react differently on the eye which then sees the various colors that compose the visible spectrum. The visible spectrum is recorded as a mixture of red, orange, yellow, green, blue, indigo, and violet. It can be readily demonstrated that white light results when the PRIMARIES (red, green, and blue) are mixed together in over-lapping beams of light. (NOTE: These are not the primaries used in mixing pigments.) Furthermore, the COMPLEMENTARY or secondary colors (magenta, yellow, and cyan) may be shown with equal ease by mixing any two of the primary colors in overlapping beams of light. Thus, red and green light mixed in equal intensities will make yellow light; green and blue will produce blue-green light which is termed cyan; and blue and red light correctly mixed will render magenta (a purplish red).

It should be noted that a few modern texts vary the treatment of the color scale slightly from the seven spectral colors. This is due partly to developments in the mixing values of pigments (paints). This difference in approach is based on a theory that the retina of the eye is equipped with three varying groups of nerves, sensitive roughly to red, green, and blue-violet light.


WHITE LIGHT
PRISM
INFRA-RED
(INVISIBLE)
RED 700 mμ
YELLOW 590 mμ
GREEN
BLUE-GREEN
BLUE 500 mμ
VIOLET
400 mμ
ULTRA-VIOLET
(INVISIBLE)
VISIBLE SPECTRUM

REFRACTION OF LIGHT BY A PRISM. THE LONGEST RAYS ARE INFRARED; THE SHORTEST, ULTRAVIOLET.


WAVELENGTHS IN MILLIMICRONS
10-6
10-4
10-2
1
10 2
10 4
10 6
10 8
10 10
10 12
10 14
10 16
COSMIC RAYS
GAMMA RAYS
X-RAYS
ULTRA-VIOLET RAYS
INFRA-RED RAYS
HERTZIAN WAVES
RADIO WAVES
LONG ELECTRICAL OSCILLATIONS
VISIBLE SPECTRUM
400 mμ
700 mμ

AT-42

Figure 3-22.—Electromagnetic wavelengths and the refraction of light.

SOUND

BASIC CONSIDERATIONS

The term sound as generally used refers to hearing; but when used in physics, the term has to do with a particular type of wave motion and with the generation, propagation, transmission, characteristics, and effects of those waves.

One example of the generation and propagation of sound waves is the tuning fork discussed earlier in this chapter. Any object which moves rapidly to and fro, or which vibrates rapidly in such a manner as to disturb the surrounding medium, may become a sound source. Sound requires three components—a source, a medium for transmission, and a detector. As widely different as sound sources may be, the waves they produce have certain basic characteristics.

Wave Motion

Sound waves are longitudinal type waves which rely on a physical medium for propagation and transmission. Since the waves are transmitted by the compression and rarefaction of particles of matter in the medium, they cannot be transmitted through a vacuum. Sound waves are similar to waves of other types in that they can be reflected, absorbed, or refracted according to the laws previously discussed; they are also subject to the Doppler effect.

The major differences between the waves of sound and the waves of heat and light are the frequencies, the nature of the wave, and the velocities of wave travel.

Conduction Media and Velocity of Transmission

In any uniform medium under given physical conditions, sound travels at a definite speed. In some substances, the velocity of sound is higher than in others. Even in the same medium under different conditions of temperature the velocity of sound varies. Density and elasticity of a medium are basic physical properties which govern the velocity of sound.

The velocity in centimeters per second of compressional waves may be calculated when the elasticity and density of the medium are given in cgs units by using the formula—Velocity $= \sqrt{\frac{\text{elasticity}}{\text{density}}}$. The elasticity of most liquids and solids is so much greater than that of gases that the velocity of sound is faster in them in spite of their larger densities. The coefficient of elasticity for water is 15,230 times that of air, while water has only 773 times the density of air. Because of this, sound travels over four times faster in water than it does in air.

Table 3-7 gives some velocities as found by testing and they correspond very closely to those derived from the formula. Other interesting comparisons are between lead and water and between steel and aluminum. Lead has a density which is greater than 11 times that of water, yet the velocity of sound is only slightly less in lead than in water. The density of steel is over twice that of aluminum, but due to the greater elasticity of steel, the velocity of sound is almost the same in the two.

The elasticities of most gases at equal pressures are the same, so the velocity of sound through gases is inversely proportional to the square root of their densities. For example, the density of air is almost 16 times that of hydrogen so the velocity of sound in air is slightly more than $\frac{1}{\sqrt{16}}$ or $\frac{1}{4}$ the velocity of sound in hydrogen. In the other direction, air has a density of slightly less than 2/3 the density of carbon dioxide, so the velocity of sound in air is approximately $\frac{1}{\sqrt{0.66}}$ or $\frac{1}{0.8}$ or 1.25 times the velocity in carbon dioxide. (See table 3-7 for actual values.)

Table 3-7.—Comparison of velocity of sound in various media.

Medium	Temperature (°F)	Velocity (ft/sec)
Air	32	1,087
Air	68	1,127
Aluminum	68	16,700
Carbon dioxide	32	856
Fresh water	32	4,629
Fresh water	68	4,805
Hydrogen	32	4,219
Lead	68	4,030
Salt water	32	4,800
Salt water	68	4,953
Steel	32	16,410
Steel	68	16,850

The velocity of sound in a gas, such as air, is independent of pressure, for when the pressure is increased, the density and elasticity both increase at the same ratio, and consequently the velocity is constant so long as the temperature is not changed. But if the temperature is raised, pressure being constant, the density diminishes so the velocity of sound increases. Using absolute values for temperature (Kelvin or Rankine), the velocities of sound in air are related to air temperatures by the relation $\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$. This amounts to about 2 feet per second increase for each degree Celsius rise in temperature and about 1.1 feet per second increase for each degree Fahrenheit rise in temperature. Since air temperature is usually lower at higher altitudes, the velocity of sound is also lower at these altitudes.

For a fixed temperature, the velocity of sound is constant for any medium and is independent of both the frequency and the amplitude of the sound waves.

Characteristics

Numerous terms are used to convey impressions of sounds, including whistle, scream, rumble, and hum. Most of these are classified as noises in contrast to musical tones. The distinction is based on the regularity of the vibrations, the degree of damping, and the ability of the ear to recognize components having a musical sequence.

The ear can distinguish tones that are different in pitch, intensity, or quality. Each of these characteristics is associated with one of the properties of the vibrating source or of the waves that the source produces. Thus, pitch is determined by the number of vibrations per second, intensity by the amplitude of the wave motion, and quality by the number of overtones (harmonics) which the wave contains. A sound wave can best be described by its frequency rather than by its velocity or wavelength, as both the velocity and the wavelength change when the temperature of the air changes.

PITCH. The term pitch is used to describe the frequency of a sound. The outstanding recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a sound is proportional to the number of compressions and rarefactions received per second, which in turn is determined by the vibration frequency of the sounding source.

Pitch is usually measured by comparison with a standard. The standard tone may be produced by a tuning fork of known frequency or by a siren whose frequency is computed for a particular speed of rotation. By regulating the speed, the pitch of the siren is made equal to that of the tone being measured. The ear can determine this equality directly if the two sources are sounded alternately, or by the elimination of beats by regulating the speed of the siren if the two sources are sounded together.

Sound waves vary in length; a long wavelength is heard as a low pitch, while a short wavelength is heard as a high pitch. If the sound is below 15 hertz or above 20,000 hertz, it normally cannot be heard by the human ear. The frequency range over which sound can be heard is called the audible range, and the sounds heard are known as sonics. Sounds below 15 hertz are subsonics; those above 20,000 hertz are ultrasonics.

On the musical scale the pitch refers to the standard frequency of a given note on the scale. This standard of pitch has been changed so often during the history of music that none can universally be called standard. In a few cases 256 Hz is used for the keynote, sometimes called middle C. For many scientific purposes, the A string of the violin is tuned to 440 Hz, which makes middle C 264 Hz on the diatonic scale or 261.6 Hz on the equal tempered scale. But in any of these cases, the note one octave higher than the first has a frequency twice that of the first and one an octave lower is one half the frequency of the first. Thus a pitch change from 55 Hz to 110 Hz is of just as much consequence as the change from 440 Hz to 880 Hz.

QUALITY. Most sounds and musical notes are not pure tones. They are mixtures of tones of different frequencies. The tones produced by most sources can be represented by composite waves in which the sound of lowest pitch, the fundamental tone, is accompanied by several harmonics or overtones having frequencies that are 2, 3, 4 or more times that of the fundamental frequency. The quality of a tone depends on the number of overtones present and on their frequencies and intensities relative to the fundamental tone. It is this characteristic of difference in quality that distinguishes tones of like pitch and intensity when sounded on different types of musical instruments (piano, organ, violin, etc.).

INTENSITY. When a bell rings, the sound waves spread out in all directions and the sound is heard in all directions. When a bell is struck lightly, the vibrations are of small amplitude and the sound is weak. A stronger blow produces vibrations of greater amplitude in the bell, and the sound is louder. It is evident that the amplitude of the air vibrations is greater when the amplitude of the vibrations of the source is increased. Hence the loudness of the sound depends on the amplitude of the vibrations of the sound waves. As the distance from the source increases, the energy in each wave spreads out, and the sound becomes weaker.

The intensity of sound is the energy per unit area per second. In a sound wave of simple harmonic motion, the energy is half kinetic and half potential; half is due to the speed of the particles, and half is due to the compression and rarefaction of the medium. These two energies are 90° out of phase at any instant—that is, when the speed of particle motion is at a maximum, the pressure is normal; and when the pressure is at a maximum or a minimum, the speed of the particles is zero.

Loudness is a subjective measurement of an auditory sensation which depends primarily upon the sound pressure of the stimulus, but it also depends upon the frequency and waveform of the stimulus. Intensity of sound is an objective measurement of the sound power being delivered and is usually measured as the power flowing through a unit area taken normal to the direction of the waves. One such method specifies microwatts flowing through an area of 1 square centimeter. One microwatt is equivalent to 10 ergs per second or 10^{-6} joules per second.

At any distance from a point source of sound, the intensity of the wave varies inversely as the square of the distance from the source.

As a sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave will be. It can be shown that intensity is proportional to the square of the pressure variation regardless of frequency. Thus, by measuring pressure changes, intensities of sounds having different frequencies can be compared directly.

Measurement of Sound

The range of sound that the human ear can detect varies with the individual. The normal range extends from about 20 to 20,000 vibrations per second. In the faintest audible speech sounds, the intensity at the ear is about 10^{-16} watts/cm^2. At the threshold of feeling, the maximum intensity that the ear perceives as sound is about 10^{-4} watts/cm^2.

The human ear is a nonlinear unit that functions on a logarithmic basis.

If the ear is tested with tones of any one frequency, the threshold of audibility is reached when intensity is reduced to a sufficiently low level so that auditory sensation ceases. On the other hand, the threshold of feeling is reached when intensity is increased to a sufficiently high level so that the sound produces the sensation of feeling and becomes painful. If this procedure is performed over a wide frequency range, the data can be used to plot two curves, one for the lower limit of audibility and the other for the maximum auditory response (fig. 3-23). Below the lower curve, the sound is too faint to be audible. Above the upper curve, the sensation is one of feeling rather than of hearing; that is, the sensation of sound is masked by that of pain. The area between the two curves shows the pressure ranges for auditory response at various frequencies. Note that the scales of frequency and pressure are logarithmic. An advance of one horizontal space doubles the frequency, and an advance of one vertical space multiplies the pressure by ten.

SOUND UNITS.—The loudness of sound is not measured by the same type of scale used to measure length. Units of sound measurement are used that vary logarithmically with the amplitude of the sound variations. These units are the bel and decibel, which refer to the difference between sounds of unequal intensity or sound levels. The decibel, which is one-tenth of a bel, is the minimum change of sound level perceptible to the human ear. Hence, the decibel merely describes the ratio of two sound levels. A sound for which the power is 10 times as great as that of another sound level differs in power level by

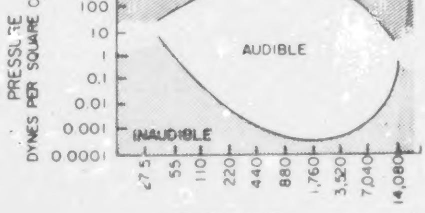


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Figure 3-23.—Field of audibility.

1 bel, or 10 decibels. For example, 5 decibels may represent almost any volume of sound, depending on the intensity of the reference level or the sound level on which the ratio is based.

In sound system engineering, decibels are used to express the ratio between electrical powers or between acoustical powers. If the amounts of power to be compared are P1 and P2, the ratio in decibels (db) is

$$\text{db} = 10 \times \log \frac{(P2)}{(P1)}$$

(NOTE: When the logarithmic base is not indicated, it is assumed to be 10.)

If P2 is greater than P1, the decibel value is positive and represents a gain in power. If P2 is less than P1, the decibel value is negative and represents loss in power.

INTENSITY LEVEL.—An arbitrary zero reference level is used to accurately describe the loudness of various sounds. This zero reference level is the sound produced by 10^{-16} watts per square centimeter of surface area facing the source. This level approximates the least sound perceptible to the ear and is usually called the threshold of audibility. Thus, the sensation experienced by the ear when subjected to a noise of 40 decibels above the reference level would be 10,000 times as great as when subjected to a sound that is barely perceptible.

ACOUSTICAL PRESSURE.—Typical values of sound levels in decibels and the corresponding intensity levels are summarized in table 3-8. The values in this table are based on an arbitrarily chosen zero reference level. Note that for each tenfold increase in power, the intensity of the sound increases 10 decibels. The power intensity doubles for each 3-decibel rise in sound intensity.

POWER RATIO.—The decibel is used to express an electrical power ratio, such as the gain of an amplifier, the output of a microphone, or the power in a circuit compared to an arbitrarily chosen reference power level. The value of decibels is often computed from the voltage ratio SQUARED or the current ratio SQUARED. These are proportional to the power ratio for equal values of resistance. If the resistances are not equal, a correction must be made.

To find the number of decibels from the voltage ratio, assuming that the resistances are equal, substitute E^2 for P in the basic equation:

$$\text{db} = 10 \times \log \frac{E2^2}{E1^2} = 10 \times \log \left(\frac{E2}{E1}\right)^2, \text{ or}$$

$$\text{db} = 20 \times \log \frac{E2}{E1}$$

To find the number of decibels from the current ratio, assuming that the resistances are equal, substitute I^2 for P in the basic equation:

$$\text{db} = 10 \times \log \left(\frac{I2}{I1}\right)^2, \text{ or}$$

$$\text{db} = 20 \times \log \frac{I2}{I1}$$

The power level of an electrical signal is often expressed in decibels above or below a power level of 0.001 watt (1 milliwatt) as

$$\text{dbm} = 10 \times \log \left(\frac{P}{0.001}\right)$$

where dbm is the power level above one milliwatt in decibels, and P is the power in watts.

The volume level of an electrical signal comprising speech, music, or other complex tones is measured by a specially calibrated voltmeter

Table 3-8.—Values of sound levels.

Sound level (decibels)	Pressure (dynes/cm²)	Intensity level (watts/cm²)
0	0.0002	10^{-16}
20	0.002	10^{-14}
40	0.02	10^{-12}
60	0.2	10^{-10}
80	2	10^{-8}
100	20	10^{-6}
120	200	10^{-4}

called a volume indicator. The volume levels read with this indicator are expressed in "v units" (vu), the number being numerically equal to the number of decibels above or below the reference volume level. Zero vu represents a power of 1 milliwatt dissipated in an arbitrarily chosen load resistance of 600 ohms (corresponds to a voltage of 0.7746 volt). Thus, when the vu meter is connected to a 600-ohm load, vu readings in decibels can be used as a direct measure of power above or below 1 milliwatt. For any other value of resistance the following correction must be added to the vu reading to obtain the correct vu value:

$$\text{vu} = \text{vu reading} + 10 \times \log \frac{600}{R}$$

where vu is the actual volume level, and R is the actual load, or resistance, across which the vu measurement is made. If the volume levels are indicated in units other than vu, the meter calibration, or reference level, must be stated with the decibel value.

ACOUSTICS

Acoustics is the science of sound, including its propagation, transmission, and effect. The performance of an announcing system or sound system when used in a room or enclosed space depends on the acoustical characteristics of the enclosure. Sound originating in an enclosed space is partly reflected and partly absorbed by enclosing surfaces such as the walls, ceiling, and floor of a room. This action introduces echoes and reverberations, which may seriously impair the quality or character of the sound.

Acoustical Disturbances

Light is often thought of first whenever reflection is discussed; however, reflection is equally common in other waves. As an example, echoes are caused by reflection of sound waves.

ECHO.—An ECHO is the repetition of a sound caused by the reflections of sound waves. When a surface of a room is situated so that a reflection from it is outstanding, it appears as a distinct echo, and is heard an appreciable interval later than the direct sound. If the surface is concave, it may have a focusing effect and concentrate the reflected sound energy at one locality. Such a reflection may be several levels higher in intensity than the direct sound, and its arrival at a later time may be particularly disturbing. Some possible remedies for this condition are:

1. Cover the offending surface with absorbing material to reduce the intensity of the reflected sound.
2. Change the contour of the offending surface and thus send the reflected sound in another direction.
3. Locate the loudspeaker in a different position.
4. Vary the amplitude or the pitch of the signal.

REVERBERATION.—Reverberation is the persistence of sound due to the multiple reflection of sound waves between sevaral surfaces of an enclosure. It is one of the most common acoustical defects of a large enclosure. Its duration varies directly with the time interval between reflections (the size of the enclosure) and inversely with the absorbing efficiency of the reflecting surfaces. The result is an overlapping of the original sound and its images. If excessive, reverberation causes a general confusion that is detrimental to speech intelligibility. The hangar deck of an aircraft carrier is an example of an extremely reverberant area. The volume is large, and the hard steel interior surfaces offer very little absorption to sound.

If a single loudspeaker is mounted in a large reverberant area, such as a hangar deck, intelligibility directly in front of the loudspeaker is satisfactory. Intelligibility decreases rapidly with an increase of either the distance from the loudspeaker or the angle between the listener and the loudspeaker's sound axis. In other words, sound from a loudspeaker in a reverberant space is composed of direct sound that reaches the listener directly without any reflection, and indirect sound that has received at least one reflection.

Intelligibility under these conditions is related to the ratio of direct sound to indirect sound. As the listener moves away from the loudspeaker, the ratio of direct sound to indirect sound at the listening position decreases, and intelligibility decreases correspondingly. Hence, in a highly reverberant space intelligibility decreases with distance from the loudspeaker.

To prevent the sound from becoming unintelligible in a highly reverberant space, several speakers can be installed about the area rather than just one. The power requirements remain the same; one 25-watt speaker could be replaced by 5 speakers, each consuming 5 watts. This would greatly increase the direct-to-indirect sound ratio.

INTERFERENCE.—Two soundwaves moving through the same medium at the same time will advance independently, each producing the same disturbance as if it were alone. The resultant of the two waves can be obtained by adding algebraically the ordinates (instantaneous magnitudes) of the component waves.

Two sound waves of the same frequency, in phase with each other and moving in the same direction are additive. The resultant wave is in phase with, and has an amplitude equal to, the sum of the component waves.

Two sound waves of the same frequency, in phase opposition and moving in the same direction, are subtractive. If the component waves have equal amplitudes, the resultant wave is zero. This addition or subtraction of waves is often called interference.

Two sound waves of slightly different frequency and moving in the same direction produce a beat note. If the two waves originate from two vibrating sources at the same point, and the frequency of one wave is one vibration per second greater than that of the other at a particular instant, the sources will produce additive disturbances at some points and subtractive disturbances at some other points on the relative positions of the waves. These changes will continue to occur as long as the sources are kept vibrating.

The resultant wave has a periodic variation in intensity at a frequency equal to the difference between the original frequencies of the component waves. The difference frequency, referred to as the beat frequency, produces a type of pulsating interference particularly noticeable in sound waves. The effect of beat frequency, called beats, produces alternately loud and soft pulses or throbs. The effect is most pronounced when the component waves have equal amplitudes.

RESONANCE.—Resonance, or sympathetic vibration, is a common problem encountered in acoustics. It is somewhat more serious than some of the other problems discussed, because the possibility exists for damage to equipment. Reverberation and resonance are frequently confused, but they are distinctly different in nature. Reverberation is a result of the reflection of sound waves and of the interaction between the direct and reflected sound. There is only a single source involved. In resonance, however, the offending object becomes a sound source under certain conditions. This may be explained by the following example:

Assume that the natural frequency of vibration of a steel shaft, which is weighted on one end and held firmly on the other, is 25 vibrations per second. Suppose that with the system at rest, a sound wave produces a force which acts on the shaft with a to-and-fro motion 125 times per second. This force sets the system vibrating at 125 vibrations per second. These vibrations would be of a small amplitude because the rod and weight are trying to vibrate at their natural rate of only 25 vibrations per second. During part of the time the system is resisting the driving force. The motion of the system in this case is called a forced vibration.

If the force is slowed from 125 vibrations per second to the shaft's natural frequency of 25 vibrations per second, the amplitude of vibration becomes very large. The amplitude will build up to a point where the driving force is enough to overcome the inertia of the system.

When these conditions exist, the system is said to be in resonance with the driving force, and sound waves are produced by this vibration.

A common example of resonance is found in a crystal oscillator circuit. When an alternating voltage is applied to a crystal that has the same mechanical (resonant) frequency as the applied voltage, it vibrates and only a small applied voltage is needed to sustain vibration. In turn, the crystal generates a relatively large voltage at its resonant frequency.

MASERS AND LASERS

The maser (Microwave Amplification by Stimulated Emission of Radiation) is an important member of the rapidly growing family of quantum electronic devices. The optical maser, called the laser (Light Amplification by Stimulated Emission of Radiation), operates in the visible and near infrared portion of the electromagnetic spectrum.

The feasibility of an optical maser was first suggested in 1958. The first operating laboratory model was constructed in 1960, less than 2 years later. Research, development and application of the laser are currently proceeding at a pace exceeding that of any other device in the history of electronics.

THEORY OF OPERATION

The generation of coherent radiation in the visible region of the electromagnetic spectrum involves interaction of radiation and matter. (See fig. 3-24.) If the magnitude of an observable quantity, in some or all of its range, is always a multiple of a definite unit, then that unit is called a quantum (of the quantity). The quantum of electromagnetic energy is the PHOTON. The photon is the quantum of energy (E) and is determined by:

$$E = h \times f$$

where: h = Planck's constant of 6.624×10^{-27} erg second
f = frequency

A given ion (or atom) can make the transition to a higher energy level by absorbing a photon from an electromagnetic field. It can make a transition to a lower level in either of two ways: spontaneous emission (a random process), or stimulated emission (a coherent process—the phase of the impinging wave is retained in both time and space).

When radiation of the proper frequency enters an area containing ions in thermal equilibrium, it will strike an ion. The ion struck will, if at the upper energy level, transfer to the lower energy level by stimulated emission; but if it is at the lower energy level, it will transfer to the upper level via absorption. Since under equilibrium conditions (fig. 3-25) there are always more ions at the lower energy level than at the higher level, the overall net effect is absorption. If it were possible, however, to begin the operation with more ions in the high energy level than in the low energy level, the reverse would be true. Then, entering electromagnetic energy of the correct frequency would cause net stimulated emission (radiation of coherent waves).

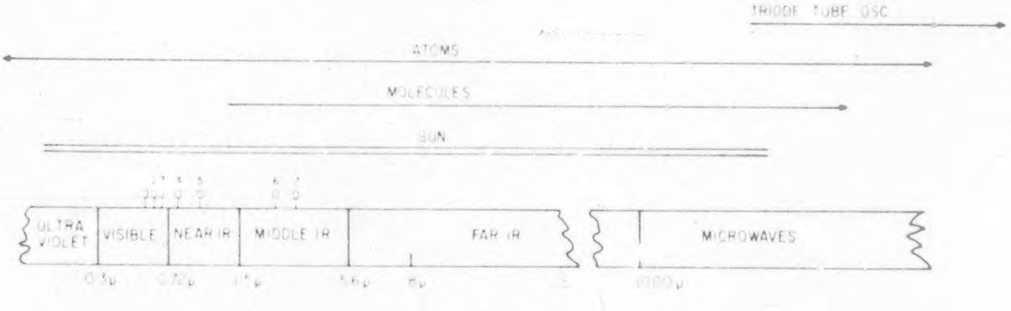

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Figure 3-24.—Spectral range of sources of electromagnetic waves.

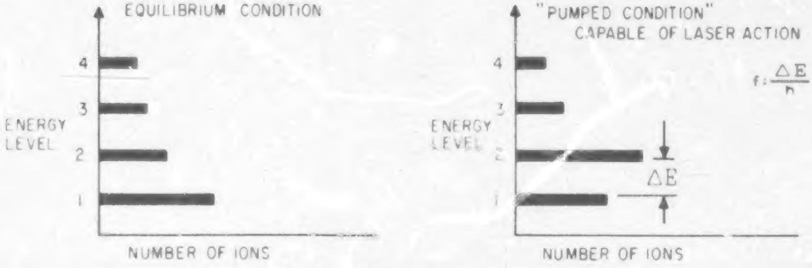

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Figure 3-25.—Energy levels of typical laser materials.

Several different techniques for producing ion population inversion (switching energy levels) are employed. The method commonly used in solid state lasers is described in terms of ruby, an aluminum oxide containing chromium. The energy levels responsible for the absorption process are shown in figure 3-25. An ion in level 1 absorbs green light and goes to level 3. It rapidly gives up energy in the form of heat and drops to level 2. The mean time that the ion remains at the metastable level, level 2, is on the order of 1 millisecond (about 200 times as long as at level 3); then it spontaneously returns to level 1 by emitting a particular frequency in the red region of the spectrum. If the crystal is illuminated with sufficient green light of the correct wavelength, the population inversion to level 2 can be maintained. This illumination is commonly termed "pumping."

If the material is properly selected and sufficiently pure, the stimulated emission can be limited to specific frequencies; i.e., frequencies that are known and determined by the physical properties of the elements involved.

LASER OPERATION

The active ion makes a transition from energy level 1 to the pump level (level 3) when it absorbs energy from the pump source. The ideal pump source would emit photons of only the desired energy (frequency); however, since such sources are rarely available, it is usually necessary to compromise and use white light. This pump energy could be focused on the crystal by sunlight, electronic flashtube, or any other sufficiently intense source.

The ion rapidly falls from the unstable pump level to the metastable level by a photon transition. The metastable level tends to become heavily populated if the pump rate is sufficiently high to put ions into the metastable level faster than they drop back to level 1 by spontaneous emission.

After slightly more than half of the ions have been pumped from level 1 to the metastable level (several hundred microseconds for a typical ruby laser), any spontaneously generated light at the correct frequency ($f = \frac{E}{h}$), corresponding to the energy difference between the ground and metastable energy levels, will cause net stimulated emission. The device will generate coherent electromagnetic energy, coherent light. Because of the design of the equipment the light generated will be of a given frequency, will have a fixed phase relationship, and will be radiated parallel to the longitudinal axis through the lightly silvered end of the laser rod.

PRACTICAL REQUIREMENTS

A practical laser device must meet the following requirements:

1. Be of a material (gas or solid) which emits

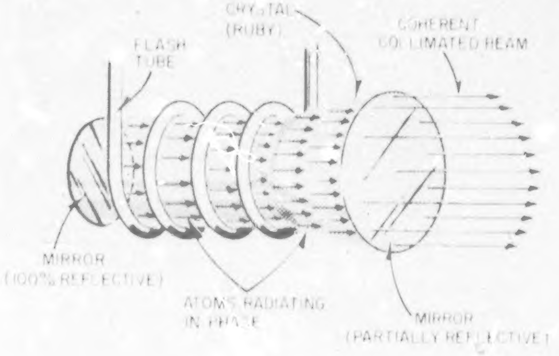
light of the desired frequency and is transparent to that frequency. The first gaseous laser, using a helium-neon mixture, emitted light at a wavelength of 1.15 microns (1.15×10^{-6} meters) or 260 terahertz (2.6×10^{14} Hz). The bandwidth spectrum of the emitted light was about 25 kHz because of frequency-pulling caused by mechanical vibration in the structure.

2. Be of adequate purity. Impurities tend to absorb or refract the emitted energy, interfering with the laser action, lowering efficiency and causing unwanted hotspots.

3. Be encapsulated to promote optimum efficiency. Proper design insures maximum coupling of pump energy to the laser. Correct dimensioning insures the maximum level of stimulated emission in the desired direction of propagation.

4. Have an efficient pump source, that is, a source which will maintain the desired energy level inversion with the minimum amount of applied energy. This increases efficiency and decreases heat dissipation problems. The ruby laser has two pump frequency bands, centering on 4,100 and 5,600 angstroms (1 angstrom = 10^{-10} meter).

The laser shown in figure 3-26 is refined as follows: a highly pure ruby crystal is grown, machined and polished to a right circular cylinder using techniques developed by transistor technologists. One end is polished optically flat and silvered to become completely reflective to visible frequencies. The other end is also polished optically smooth, but is only partially reflective. The crystal is machined to an exact multiple of the wavelength of the desired operating frequency of the laser; the crystal thus acts as a resonant chamber, continuously reflecting energy along the longitudinal axis. The lightly mirrored end will transmit a portion of the energy which strikes normal (perpendicular) to its surface.



AT.152

Figure 3-26. –Simple laser.

The emitted energy can be focused or otherwise treated in the same manner as ordinary light. It differs from normal light in that it is composed of an extremely narrow band of frequencies and it has a definite spatial phase relationship.

In early November 1962, IBM, GE, and Lincoln Laboratory announced simultaneous development of a gallium arsenide diode. This laser has a much higher efficiency potential and far simpler modulation mechanism than its predecessors. It constitutes the next major step forward in laser development. Excited by high current densities (greater than 10,000 amp/cm^2) at its junction, it emits coherent light in the near IR (8,400 angstroms) from its polished surface with a beam width on the order of 4 degrees.

The laser is destined to become an important segment of the electronics industry. Most high frequency systems (radar, guidance, communications) will employ masers of some type. In the optical region, the laser, only a theory a few years ago, fulfills for the first time the dream of scientists since Newton—a source of coherent light.

APPLICATIONS

It is anticipated that lasers and masers will find extensive applications in many major fields. In view of the known characteristics of masers and lasers, studies are currently conducted to find specific applications in the following fields:

1. Surgical tool. Using a converging lens system, the laser beam can be focused to approach a true point source of light at the focal point. The theoretical limit of the spot diameter would be approximately 1 wavelength (6,943 angstroms for the ruby laser). The entire energy

radiated could be focused at one spot, creating at that spot a temperature more intense than that at the surface of the sun. This laser beam could be used as a superscalpel, or welding torch, for surgical operations on the human eye and nerves.

2. Communications device. The laser beam can be used as a super-directional communications link in a new uncluttered part of the spectrum. Many researchers are experimenting with methods of modulating the laser beam. One method of modulating the beam with audio frequencies has already been developed.

3. Energy transfer device. The laser beam constitutes the most intense form of energy propagation yet put at man's disposal. Laboratory models have been used to burn holes through sheet steel. If a sufficiently high-power laser were available, it could radiate sufficient energy from the ground to power satellites or robot helicopters, with practically no energy loss due to transmission.

4. Frequency and distance standard. Since the frequency emitted by a laser depends upon the atomic properties of the material used, the frequency would be known with a high degree of accuracy and would remain constant for the operating life of the laser. The laser will permit all research laboratories to maintain an accurate secondary frequency/distance standard. (1 meter = 1,650,763.73 wavelengths of the orange-red spectral line of krypton 86.)

5. Precision radar system. Lasers have such high spectral purity and directionality that they can be used as precision radar systems. An earth-based laser radar, with an optical system only inches in diameter, has such a high resolution that the beam at the surface of the moon would only be a few miles wide. In a test at the MIT Lincoln Laboratory, the beam of a laser was focused on the moon by a telescope, and returned radiation was detected by a photomultiplier tube after being collected by another telescope. The illuminated area on the surface of the moon was estimated to be 2 miles in diameter.

6. Undersea utilization. Researchers are attempting to develop a laser which will operate in the blue-green portion of the visible spectrum. Water is quite transparent at this band of frequencies. A secure undersea communications link or an undersea optical radar has understandably desirable qualities.

7. Guidance systems. The "smart bombs" used successfully in Viet Nam in the spring of 1972 had either television or laser guidance systems. Both required favorable weather conditions. The laser system added only $3,100 to the cost of each bomb, whereas the television system added $15,000 per bomb.

8. Land surveys. RCA is producing a portable laser land surveying system under a contract funded by the U.S. Forest Service. Two back-packageable units are used at distances of up to one mile apart. The pulsed laser beam is fired vertically and the receiving telescope is elevated as much as 45° until it clears all intervening obstacles and picks up the beam. Accuracy is ± 1 foot over a distance of 1 mile. The system can readily be adapted to situations where triangulation is required.

CHAPTER 4

SPECIAL TOOLS AND MATERIALS

A skilled technician can be identified by the way he handles and cares for his tools and materials. Tools are a costly investment and should be cared for and used to full advantage. There seems to be something about good tools that stimulate an average technician to turn out above average work. This fact alone more than justifies the slightly higher cost of quality tools. Even more important is the fact that low quality tools become defective more readily and can result in injury to the user or damage to the equipment undergoing repair.

Similarly, proper use of quality materials improves the performance of any maintenance task and reduces the possibility of new failures. The primary duties of all maintenance personnel are to become thoroughly familiar with the tools and materials of his trade and be proficient in their care and use.

Some excellent sources of information regarding handtools and their use and care are the Rate Training Manuals, Airman, NavPers 10307-C, and Tools And Their Uses, NavPers 10085-B. Since these manuals are basic to all aviation ratings, the material covered in them is not duplicated in this discussion; review of that material should be accomplished before proceeding with this chapter.

SPECIAL TOOLS

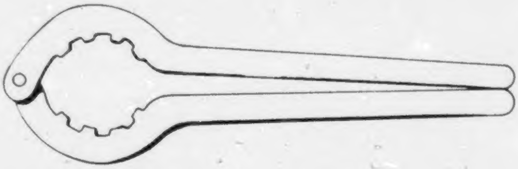
A wide variety of special tools is required to maintain the modern aircraft of today's Navy. These tools are furnished by the manufacturers of the aircraft, engines, and related equipment.

Proper use of special tools greatly reduces the man-hours required for maintenance work.

These tools are listed in allowance lists published by the Naval Air Systems Command, and their use is explained in the Maintenance Instructions Manual covering the particular aircraft, engine, or piece of equipment for which they were designed. An example of a special tool that is required for special maintenance of equipment is the cable assembly connector wrench. This wrench is used to remove the sonar dome from the electrical special purpose cable assembly. (See fig. 4-1.)

NONMAGNETIC TOOLS

Tools made of nonmagnetic materials are available through normal supply channels. They are used for performing specific maintenance functions on certain classes of equipment or components—such as maintaining the detecting heads of MAD equipment. These tools, normally made of beryllium-copper, are used because steel tools may become magnetized through normal use.



AT.76

Figure 4-1.—Cable assembly connector wrench.

Restricting the use of the nonmagnetic tools to the purpose for which they are intended will increase their value to the technician. Use of these tools for general maintenance would allow them to transfer metal or other foreign particles into electronic equipment. The gears and bearings of the detecting head are easily fouled by small particles of dust or metal. In addition to mechanical fouling, the introduction of metal particles that are magnetized would cause magnetic noise in the detecting head.

Nonmagnetic tools should also be used in tuning RF circuits which are susceptible to frequency change resulting from the introduction of new magnetic fields (or the distortion of the existing magnetic fields). Many slug-tuned IF circuits involve this potential trouble.

Good general maintenance practice involves wiping the tools before use and again after use. This is especially advisable in the case of nonmagnetic tools. A lint-free cloth dampened with a suitable cleaning solvent may be used for this purpose.

Nonmagnetic metals are usually softer than steel, so use of these tools for general maintenance could also damage the tools.

INSULATED TOOLS

Safety considerations require use of insulated tools whenever the danger of electrical shock or short circuit exists. Many types of tools are available in insulated form directly through supply channels at little or no additional cost. These tools should be obtained and used whenever available. However, many types of insulated tools are not readily available (or are available only at considerable added expense). If essential, these tools should be procured or conventional tools may be modified. Insulated sleeving may be put on the handles of pliers and wrenches and on the shanks of screwdrivers. Tools modified in this manner should be used only for low voltage circuits because of the limitations of the insulating materials. For higher voltage uses, special insulating handles are available for many of the common types of tools.

In some instances, it is necessary to use tools which are made of insulating material, rather than merely having an insulating handle. In these instances, the tools should be requisitioned through normal supply channels, if possible. If they are not available through normal supply channels, they may be purchased on the open market.

RELAY TOOLS

Two of the more common handtools used to repair relays are the burnishing tool and the point bender. The use of these two items is discussed in the following paragraphs.

Burnishing Tool

Many relays have been damaged or ruined by the use of sandpaper or emery cloth to clean the contact points. Use of these abrasives causes bending of the contacts; and attempts to straighten them with long nosed pliers cause further damage, eventually requiring replacement of the relays. This can be avoided by using a burnishing tool to clean dirty contact points.

Figure 4-2 illustrates a burnishing tool being used on a relay.

Two common types of burnishing tools are stocked in supply activities and may be obtained through normal supply channels. These two common burnishing tools are 2 33/64 inches and 5 inches in length.

Be sure to clean the tool thoroughly with alcohol and do not touch the tool surface with your fingers prior to use.

Burned and pitted contacts cannot be repaired by burnishing. Relays having trouble this serious should be replaced.

Point Bender

Another handy tool that is often found in a toolbox is a point bender. The point bender (fig. 4-3) is used to straighten bent relay contacts. This bender can be fabricated locally from 0.125-inch diameter rod stock according to the dimensions in the figure.

WIRE AND CABLE TOOLS

An innovation in electrical connectors is the taper pin electrical connector for aircraft. The taper pin works on the principle of driving a taper wedge into a tapered hole and depending

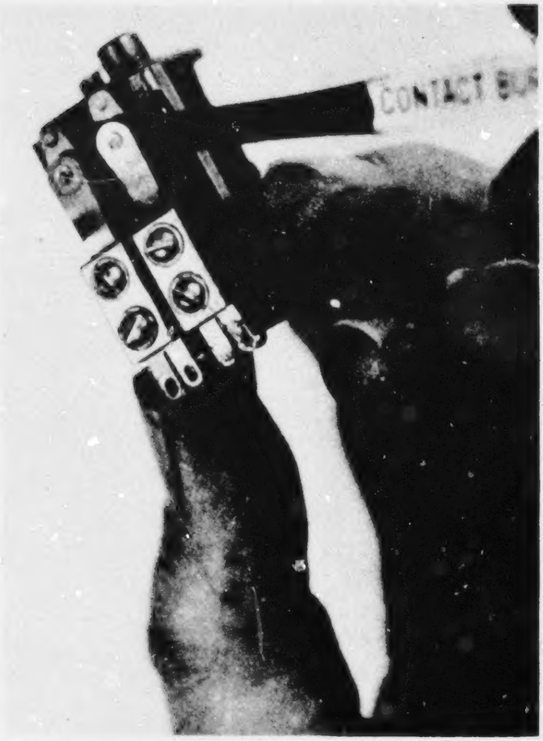


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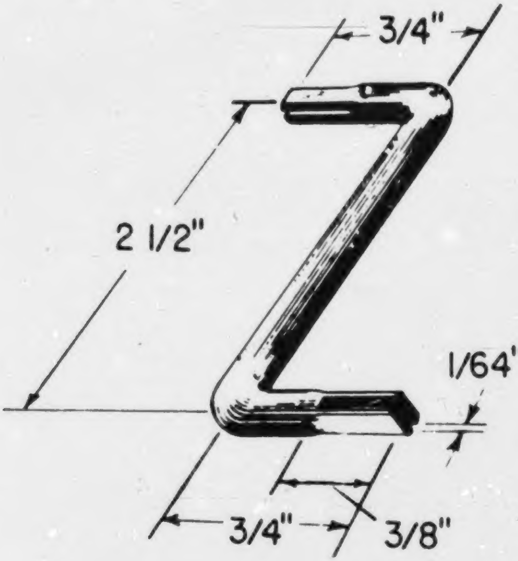
Figure 4-2.—Burnishing tool.



AT.79

Figure 4-3.—Point bender.

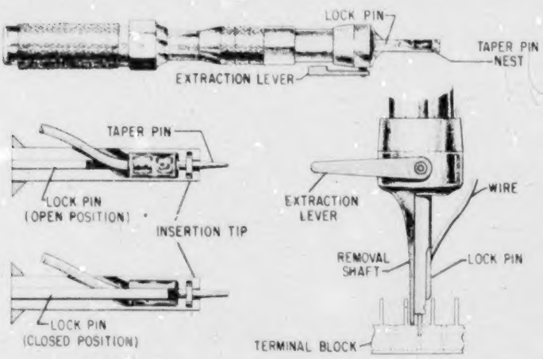
on friction to retain the pin in the hole. The taper pin connector makes a very good electrical and mechanical connection because of the high metal to metal contact pressure developed during the driving action of the insertion tool. Taper pins permit circuit changes to be quickly and easily performed without a soldering iron. Tests show that vibration and corrosion, over a period of time, improve the electrical continuity and increase the mechanical pulling force required to remove a taper pin. Another advantage of taper pins is the accessibility of test points for voltage and circuit continuity checks.

Insertion and Removal

A special tool, shown in figure 4-4, is used to properly insert the taper pin into the terminal block socket. The insertion tool has a calibrated driving spring, a calibrated pull test spring, a taper pin captive key, and a taper pin removal feature.

The driving spring adjusts to apply the proper driving impact to the pin. The pull test spring adjusts to apply the correct pull force on the pin to check for proper pin insertion. The captive key insures that each taper pin has a 100 percent pull test before the tool is disengaged from the pin. The removal lever is rotated to remove the taper pin from the terminal block socket.

In order to maintain the reliability of the system, it is imperative that the taper pin be properly inserted into the terminal block sockets. Pushing the pins into the sockets with the fingers or pliers will not make them stay—they must be driven in with the insertion tool. The tool must be calibrated to insure that the proper pressures are used. When inserting the taper pins, the insertion tool must be held at right angles to the terminal block, and pushed


LOCK PIN
TAPER PIN NEST
EXTRACTION LEVER
TAPER PIN
LOCK PIN (OPEN POSITION)
INSERTION TIP
LOCK PIN (CLOSED POSITION)
EXTRACTION LEVER
WIRE
REMOVAL SHAFT
LOCK PIN
TERMINAL BLOCK

AE.36

Figure 4-4.—Taper pin insertion and removal tool.

straight toward the terminal block without twisting the tool. The pins are very sensitive to twists, which could cause a faulty connection or a broken pin. Bent or broken pins should always be replaced. However, if correct installation procedures are followed, a taper pin may be installed and removed as many as 25 times before a replacement is necessary. A properly installed taper pin will pass the pull test of the insertion tool.

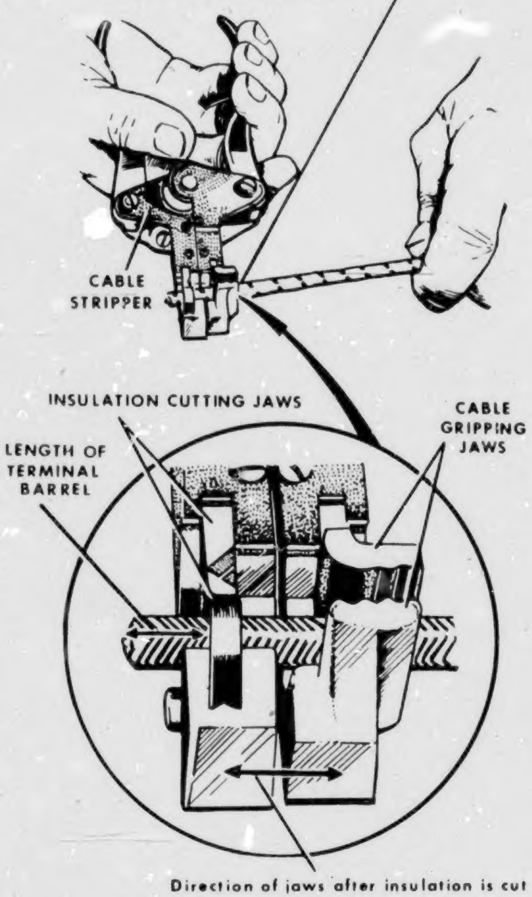
Three different sizes of taper pins are used to terminate wires from size 16 through size 22. The sizes are identified by color coding of the insulating sleeves. A crimping tool is used to attach the taper pin to the wire. This taper pin crimping tool is similar to other types of wire terminal crimping tools, such as those discussed later in this chapter.

Stripper

Nearly all wire and cable used as electrical conductors are covered with some type of insulation. In order to make electrical connections with the wire, a part of this insulation must be removed, leaving the end of the wire bare. To facilitate the removal of this insulation, use a wire and cable stripping tool similar to the one shown in figure 4-5.

Although several variations of this basic tool are available, the most efficient and effective is the type illustrated. Its operation is extremely simple—insert the end of the wire in the proper direction to the depth to be stripped, position the wire so that it rests in the proper groove for that size wire, and squeeze. The tool functions in three steps as follows:

1. The cable gripping jaws close, clamping the insulated wire firmly in place. The wire must be inserted so that the jaws clamp the main section of the wire rather than the end to be stripped.


After cable has been placed between gripping and cutting jaws, squeeze handles together

CABLE STRIPPER
INSULATION CUTTING JAWS
CABLE GRIPPING JAWS
LENGTH OF TERMINAL BARREL
Direction of jaws after insulation is cut

AE.37

Figure 4-5.—Wire and cable stripper.

2. The insulation cutting jaws close, cutting the insulation. If the wire is not inserted in a groove, the conductor will also be cut. If the wire is positioned into too small a groove, some of the strands will be severed. If the groove is too large, the insulation will not be completely severed. Inserted properly into the correct groove, the insulation will be cut neatly and completely, and the wire will not be damaged.

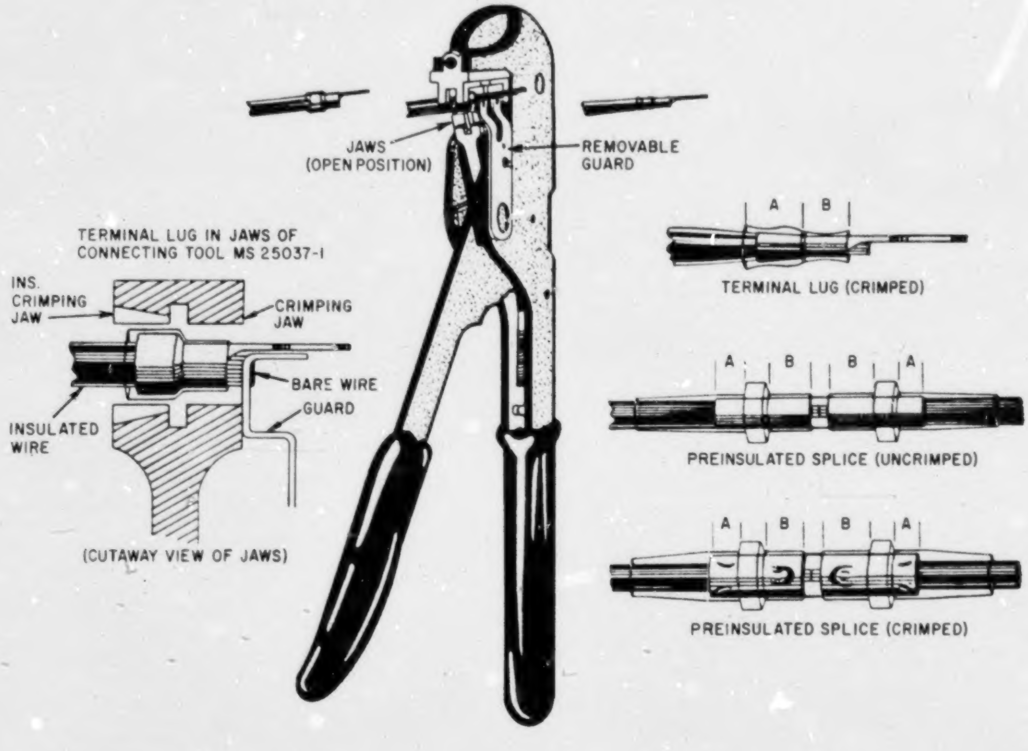
3. The two sets of jaws separate, removing the clipped insulation from the end of the wire.

If cable and wire strippers of this type are not available, notches may be cut in the jaws of diagonal pliers or pocket fingernail clippers, using jeweler's files. Care must be taken to file the grooves into the proper positions in opposing jaws, and the size of the groove must be appropriate for the size wire on which it is to be used. When properly modified, these tools will perform satisfactorily if the more desirable stripper is not available.

CRIMPING TOOL

Type MS 25037-1

The standard tool MS 25037-1, issued for crimping solderless terminals, is for use with standard insulated copper terminal lugs manufactured according to MS 25036. The standard tool employs a double jaw to hold the terminal lug or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when the terminal is inserted, as shown at the left in figure 4-6. When the tool is used correctly, a deep crimp is placed in the B


JAWS
(OPEN POSITION)
REMOVABLE
GUARD
TERMINAL LUG IN JAWS OF
CONNECTING TOOL MS 25037-1
INS.
CRIMPING
JAW
CRIMPING
JAW
BARE WIRE
GUARD
INSULATED
WIRE
(CUTAWAY VIEW OF JAWS)
A
B
TERMINAL LUG (CRIMPED)
A
B
B
A
PREINSULATED SPLICE (UNCRIMPED)
A
B
B
A
PREINSULATED SPLICE (CRIMPED)

AE.38

Figure 4-6.—Crimping tool MS 25037-1.

area of terminal lugs and splices, as shown in diagrams on the right of the figure. A shallow crimp is applied to the portion of the terminal or splice which extends over the insulation of the wire, as indicated by the A area in the diagrams. This clamping action is provided by a recessed portion in the other side of the divided jaw. A guard, which should be in the position shown when crimping terminals, aids in proper positioning of the terminal. However, the guard must be moved out of the way when the tool is used for crimping splices.

Without the guard, the tool may be used incorrectly; for example, the terminal might be inserted from the wrong side of the tool. The result is that the deep crimp is placed in the A area of the terminal or splice and, although the wire may be held securely in place, the connection is poor. Common sense indicates that the deep crimp must clamp the metal of the terminal to the bare metal of the wire in order to provide a good electrical and mechanical connection.

The MS 25037-1 tool requires occasional checking. A No. 36 (0.106) drill rod should not be able to enter the smaller (red or blue) nest when the tool is fully closed. If it does enter, have the tool repaired.

Instruction in proper crimping procedure should be furnished to all who need to make solderless terminal connections. Handbook of Installation Practices for Aircraft Electric and Electronic Wiring, NA 01-1A-505, contains detailed procedures for using many solderless connector tools.

Type MS 3191-3

This tool is the latest standard crimping tool designed specifically for use with type MS 3191 contacts for electrical connectors. It features interchangeable heads to accommodate various size terminals. It may be used with the turret (fig. 4-7 (A)) for normal use, or without the turret (fig. 4-7 (B)) for eyeball crimping.

Before using the tool, the correct selection must be made on the positioner head and also on the indentor gap selector plate. To release the turret for indexing, press the trigger and the spring-loaded turret snaps out to its indexing position. Select the desired position from the color-coded nameplate and rotate the turret to aline the selected positioner with the index. Depress the turret until flush, and the turret will automatically lock into place. To prevent further indexing, insert lockwire through the hole provided in trigger.

To crimp a terminal, select the proper size and type terminal and insert the prepared wire into the contact pocket until the wire seats on the bottom. The wire should be visible through the inspection hole and the insulation should enter the contact insulation support. Insert the contact and wire into the terminal crimping tool, making sure that the contact is properly seated in the positioner. Actuate the crimping tool handles to crimp the contact and wire. At the completion of the stroke the ratchet releases; open the handles and remove the crimped contact from the tool.

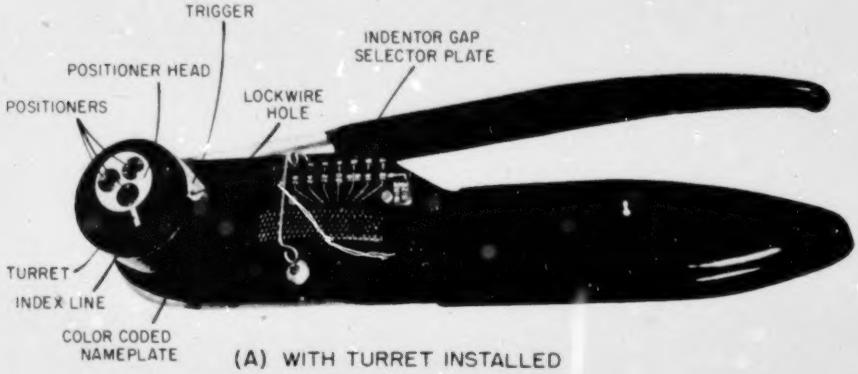
Inspect the crimped terminal and wire. The wire must be visible through the inspection hole. The insulation must be inside the insulation support. The crimping indents must be positioned between the inspection hole and the front of the insulation support. The contact must not be bent. The crimped contact is now ready to be installed into a connector.

For eyeball crimping, remove the head assembly from the tool. Select the proper wire size and move the thumb button until the pointer is alined with the selected wire size on the indentor gap selector plate. Holding the contact in the crimping tool, slowly close the handles and at the same time position the contact so that the indentors are positioned midway on the contact barrel. Insert the wire, making sure it is bottomed in the contact, then close handles fully.

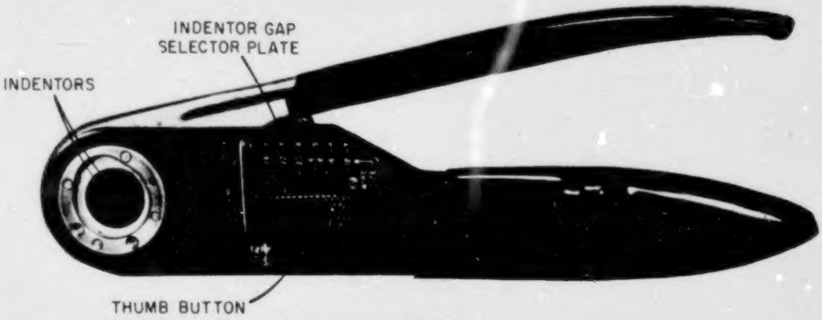
After releasing the handles, remove and inspect the crimped contact. The contact must not be fractured, and the conductor must be visible in the inspection hole.

DIAGONAL PLIERS

Diagonal pliers are described briefly in Tools And Their Uses, NavPers 10085-B. The following discussion describes a modification which is advantageous when the diagonal pliers are used in the maintenance of equipment aboard aircraft where working clearances are likely to be close.


TRIGGER
INDENTOR GAP SELECTOR PLATE
POSITIONER HEAD
LOCKWIRE HOLE
POSITIONERS
TURRET
INDEX LINE
COLOR CODED NAMEPLATE

(A) WITH TURRET INSTALLED


INDENTOR GAP SELECTOR PLATE
INDENTORS
THUMB BUTTON

(B) WITH TURRET REMOVED

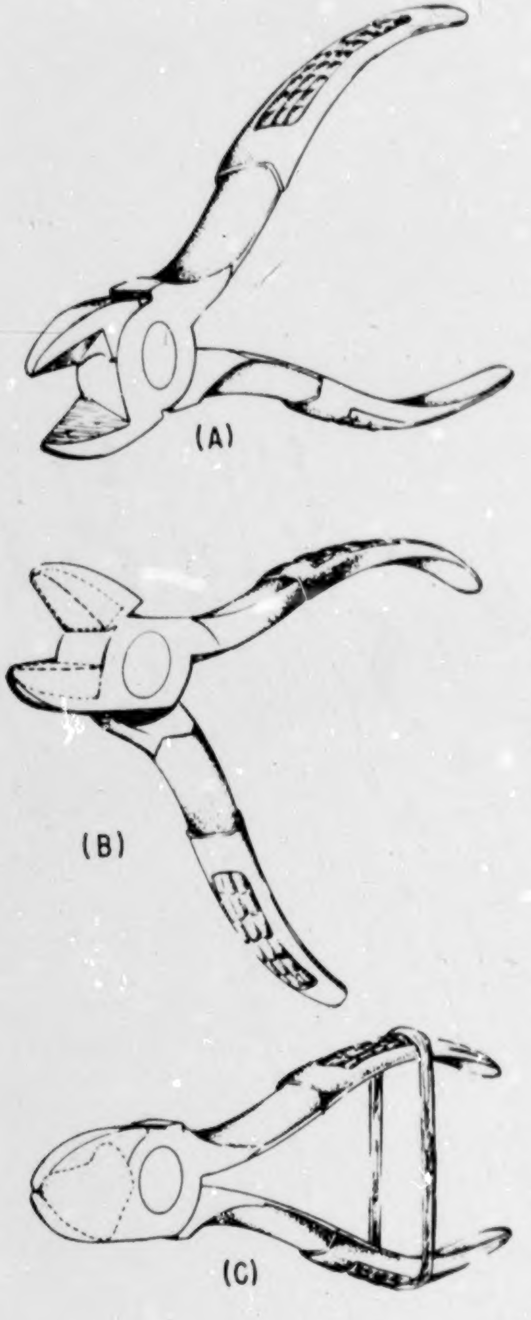
AE.39

Figure 4-7.—Crimping tool MS 3191-3.

The diagonal pliers (fig. 4-8) have been modified by adding potting compound to the jaws. This prevents loss of small pieces of wire into the equipment when cutting wire. The potting compound also allows the technician to cut the wire without holding onto the piece being cut away. (Figure 4-8 (A) shows the diagonals before being modified.) If you do not have a pair of these modified diagonal pliers, manufacture your own by adding potting compound. Before applying the potting compound, clean the diagonals with solvent; then secure the handles with a rubberband (fig. 4-8 (C)) and apply the compound. Allow 24 hours for the compound to dry. The jaws may be separated by slicing them apart with a single edge razor blade.

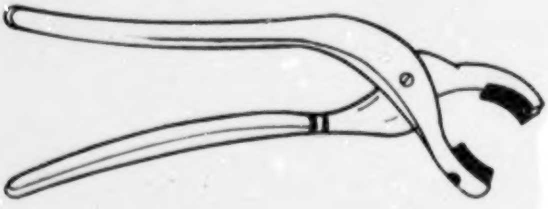
CANNON PLUG PLIERS

Figure 4-9 displays a set of special pliers used to remove threaded electrical connectors when they are on so tight that they cannot be removed by hand. A slip joint keeps its smooth gripping jaws parallel, thus preventing damage to the electrical connector during the removal operation.



AT. 80

Figure 4-8.—Diagonal pliers. (A) Without compound; (B) with compound; (C) applying compound.



AQ. 361

Figure 4-9.—Cannon plug pliers.

PRINTED CIRCUIT REPAIR TOOLS

A kit containing hand-held tools, microelement-handling units, and soldering materials, all selected because of their usefulness in repairing avionics modules, is known as an avionics module repair kit. This kit may be ordered through normal supply channels by any authorized maintenance activity. (The federal stock number is VX 4920-808-6663.) It consists of 61 items stored in the trays of a portable case. Figure 4-10 shows the upper tray of the carrying case, and figure 4-11 shows the arrangement at the bottom of the carrying case. The items are numbered in figures 4-10 and 4-11 to correspond with the numbers in table 4-1 which also lists the nomenclature of the items.

A brief description of most of the items in the kit is given below to help the technician realize how valuable this kit can be in repairing printed circuits.

Items 1-10 are used with the flexible drive shaft and handpiece assembly (items 37 and 38), which in turn are powered by the portable power pak (item 61) to do the necessary drilling, cutting, grinding, and polishing when components are removed. When these attachments are used, they should be operated at a uniform speed and applied with controlled pressure.

Item 11 contains tips for the solder extraction system, which is described later.

Item 12 is used with the small area spray system (item 41) and solvent (item 39) to clean any greasy residue from small areas to be repaired.

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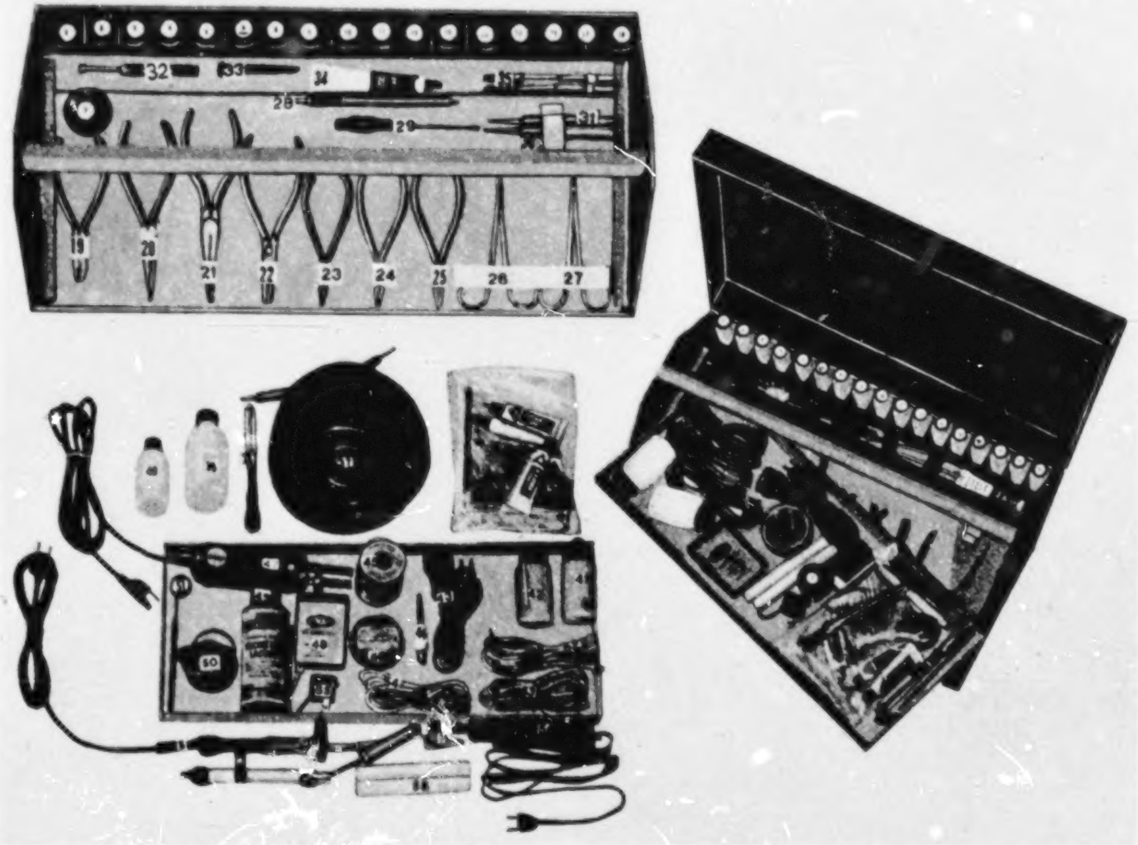

AQ.362

Figure 4-10.—Upper trays of carrying case.

Item 13 contains blades for the thermal stripper, which is discussed later.

Item 14 contains tips for the vacuum tweezer, which is discussed later.

Items 15, 16, 17 and 33 are various wrenches and screwdrivers which, when used, should be used with moderate pressure to prevent breakage or damage to the printed circuits.

Items 18, 26, and 27 are heat sinks and clamps which are used to prevent damage to components by the dissipation of the heat required to desolder or solder.

Items 19-25 are various pliers used for bending leads, cutting wire, and general circuit work.

Items 14 and 28 comprise the vacuum tweezer and cleaning system. Item 28 is a cylindrical type vacuum probe that has no valve, but only a hole open to the atmosphere. The probe is connected to the vacuum source by means of the plastic hose assembly (items 52 and 53). The appropriate tip (item 14) is attached to the end of the probe closest to the finger hole.

The probe is designed to handle small parts and provides instantaneous and positive pickup and release of parts. Effective use of the probe can prevent damage to miniature parts, as it is capable of handling items as small as 0.0006

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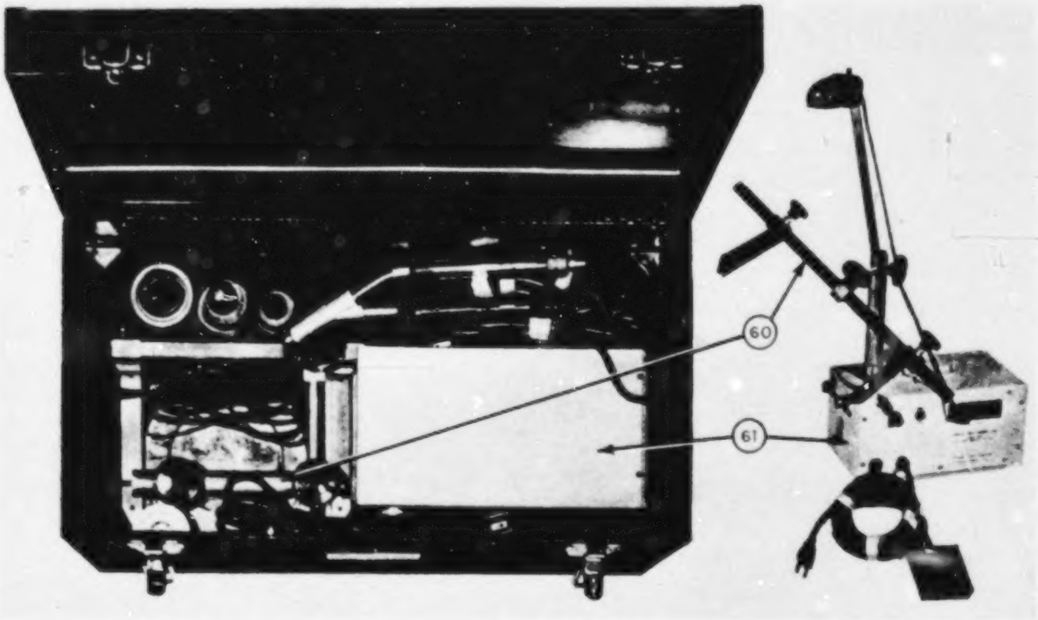


AQ.363

Figure 4-11.—Storage arrangement at bottom of carrying case.

inch in diameter. It can also pick up ceramic and glass substrate, paper-thin elements, wafers, pellets, etc. The kit contains three probe tips.

The probe operates by activating the foot switch of item 61 to produce a vacuum and then covering the hole with a finger to extend the vacuum to the tip of the probe. To release an object, simply remove the finger from the hole. Complete vacuum cleaning of electronic components can be accomplished with brush type tips.

Item 34 is high temperature lubricant which should be applied to soldering gun tips, stripper tip screws, and other areas in which heat may cause a threaded part to seize. It should be applied to the threaded part before the mating part is attached.

Item 37 is a flexible drive shaft driven by the power pak (item 61) and is used in conjunction with the handpiece (item 38) to drive the various drills, ball mills, slotting saws, and abrasive wheels.

Item 47, a thermal wire stripper (fig. 4-12) is a compact self-contained unit that uses no external transformers or power supplies. Its steel-alloy heated blades (item 13) are mounted on electrodes protruding from the front of the unit. The upper-blade-and-electrode assembly is mounted on a movable arm, which is operated by the thumb to apply pressure to close the jaws, and contains a small red button that is depressed to heat the blades.

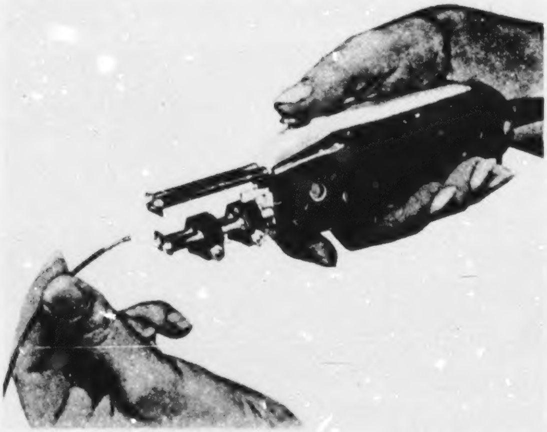
As shipped from the factory, the blades are notched to receive AWG 24 or larger wire. To meet exacting stripping requirements, the notch should be slightly larger than the diameter of the wire to be stripped. The tool can be used with wire as small as AWG 43. For wire smaller than AWG 32, however, unnotched blades should be used. Additional blades, which may be obtained

Table 4-1.—Parts list of kit items.

Item No.	Description
1-vial #1	Mandrel, screw clamp
	Mandrel, screw thread
2-vial #2	Drills, inch
	.032
	.047
	.062
	.078
	.093
3-vial #3	Ball mills, inch
	.018
	.032
	.047
	.062
	.093
	.125
	.156
	.187
	.250
4-vial #4	Brass brush 3/16" dia.
	Fiber brush 3/16" dia.
	Spare fuse
5-vial #5	Slotting saw .088" dia.
	Abrasive wheel, fine, red, 5/8" dia.
	Abrasive wheel, coarse, green, 5/8" dia.
6-vial #6	Abrasive point .163" dia., white, soft material
	Abrasive point .163" dia., red, hard material
	Abrasive point .106" dia., conical, white, soft material
	Abrasive point, .106" dia., conical, red, hard material
	Abrasive wheel, silicon carbide, red, hard material, 7/16" dia.
7-vial #7	Abrasive wheel, tapered, red, 7/8" dia.
	Abrasive wheel, tapered, green, 7/8" dia.
8-vial #8	Bristle brush, 3/4" dia.
	Bristle brush, 5/8" dia.
9-vial #9	Fine abrasive point, red, 1/4" dia.
10-vial #10	Coarse abrasive point, green, 1/4" dia.
11-vial #11	Tips, solder-extraction system, inch
	.020
	.036
	.061
	.095
12-vial #12	Nozzle tips, spray system
13-vial #13	Blades, thermal stripping system
14-vial #14	Tips, vacuum tweezer, straight with .060 ID, 45 degrees
	Tips, vacuum tweezer, angled with .060 ID
	Tips, vacuum tweezer, angled with .050 ID with soft brush at tip
15-vial #15	Allen wrench set #4, #6 & #8; Phillips screwdriver set size #0 & #1
16-vial #16	Flat screwdriver: awl set blade sizes .055, .070, .080, .100; awl size .10
17-vial #17	Socket wrench set 5/64, 3/32, 7/64, 1/8 and 5/32
	Open end wrench set 5/64, 3/32, 7/64, 1/8 and 5/32
18-vial #18	Miniature heat sinks
19	Diagonal cutting pliers 4 1/2"
20	Longhose pliers 6" CM55
21	Extra-fine needlenose pliers 6"
22	Side-tip nose cutting pliers 6"
23	Short-chain nose pliers 5"
24	Flatnose plier 4 1/2"
25	Roundnose pliers 5"

Table 4-1.–Parts list of kit items–Continued.

Item No.	Description
26	Straight heat-sink clamp
27	Curved heat-sink clamp
28	Vacuum tweezer and cleaning system
29	Utility screwdriver
30	Tweezer, serrated, nonmagnetic stainless
31	Tweezer, smooth, nonmagnetic stainless
32	Fiberglass brush
33	Handle to fit tool sets contained in vials 15, 16, 17
34	High-temperature lubricant
35	Oxide remover
36	Epoxy kit consisting of: (a) Wood spatula (b) Work platen (c) Brush (d) Mixing cup (e) Epoxy-resin cement
37	48" flexible drive shaft
38	#8 handpiece
39	4-ounce trichloroethane solvent
40	2-ounce stripvar
41	Small-area spray system
42	2-ounce bottle nalgene with #2104, 2 1/4" tube
43	Pencil soldering iron
44	Tip for pencil soldering iron
45	Energized rosin-cored solder 60/40 .032" dia.
46	Soldering paste--2-ounce
47	Thermal stripping
48	Cleaning unit
49	6-ounce silicone coating
50	2-power magnifying lens
51	Mirror extended 45 degrees
52	Hose assy, flexible plastic hose, 5' with 1 De Vilbiss #630 TA cutoff and 1 Hansen B-1-T125 fitting
53	Hose assy, clear plastic tubing, 5' with 1 Hansen B-1-T125 fitting
54	Hose assy, clear plastic tubing, 5' with 1 Hansen B-1-T125 fitting
55	Polarized plug
56	Heat probe system
57	Heat probe, directional cones
58	Spare reservoirs for solder-extraction system
59	Solder extraction system
60	Illuminated work-holding-and-positioning unit
61	Portable power pak



AQ.364

Figure 4-12.–Thermal wire stripper.

directly from the manufacturer, are left unnotched so that the user may notch them to his own requirements. Notched blades for any size of wire may be obtained on special order from the manufacturer.

CAUTION: Teflon, PVC, and silicone-rubber insulations should be stripped in a well-ventilated area because in the process a small amount of toxic gas may be emitted.

After considerable use, the stripper blades will become encrusted with residue from the wire coverings. Sometimes this residue can be burned off by the application of full heat to the blades for a minute. If heat does not burn off the residue, the residue can be easily removed with a soft wire brush without damage to the blades.

When installing new blades, carefully check the alinement of the notches and be certain that the retaining screws are tightened.

CAUTION: The stripper will not function or heat properly unless the retaining screws holding the blades are tightened as firmly as possible.

Item 59 is the solder extraction system; an example of its use is shown in figure 4-13. It is connected to the power pak (61) by a clear plastic hose contained in the kit. The vacuum outlet then sucks away the solder as it is melted with the iron. The solder extractor has a large area of heat radiation, so the person using it should be aware of its workbench placement to prevent possible burn injuries and equipment damage.

Item 60 is an illuminated work-holding-and-positioning unit (fig. 4-11) and is used to hold and position circuit boards or modules. Since the light above the unit is usually insufficient, additional light may have to be provided. When this unit is holding assemblies other than circuit boards, it will be necessary to attach chassis holders or modular holders to the top of the movable board-holder bars.

Item 61, the portable power pak, supplies compressed air and vacuum for using the solder extraction system, heat probe, vacuum tweezer, and spray unit and has a mechanical drive chuck for the turning of the flexible drive shaft handpiece assembly (item 37 and 38) during drilling, grinding, and polishing operations. In addition, the pak has three 110-volt a-c electrical outlets that furnish required power for the various tools. Foot operation of the power pak–to obtain compressed air, vacuum, or power–is controlled by a microswitch. However, the application of more or less pressure to the foot switch does not permit control of speed.

AIRCRAFT HARDWARE AND CONSUMABLE MATERIALS

MOUNTING PARTS

Items of hardware used when installing equipment in aircraft are specified in the applicable Maintenance Instructions Manual. In all instances, the proper parts should be used; if substitution becomes necessary, care must be taken that the substitute item is satisfactory in all respects.

It is not always desirable to use the same mounting parts that were removed from the installation. Prior to reinstalling the same items, an inspection must be made to insure that the parts are of the type specified, and are not defective or damaged. It must also be determined that instructions do not forbid their reuse. Then, and only then, may the removed parts be reinstalled.

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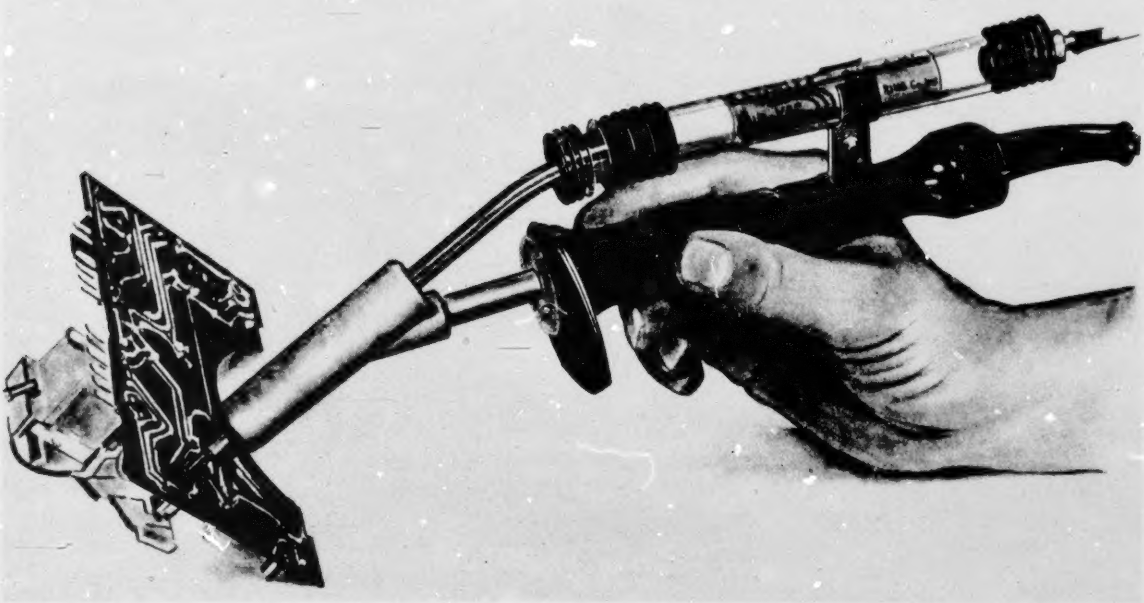

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Figure 4-13.—Solder extraction tool.

General information regarding such mounting parts as screws, nuts, bolts, washers, etc., is included in various Rate Training Manuals. Aircraft Structural Hardware for Aircraft Repair, NA 01-1A-8, is a valuable source for detailed information.

TURNLOCK FASTENERS

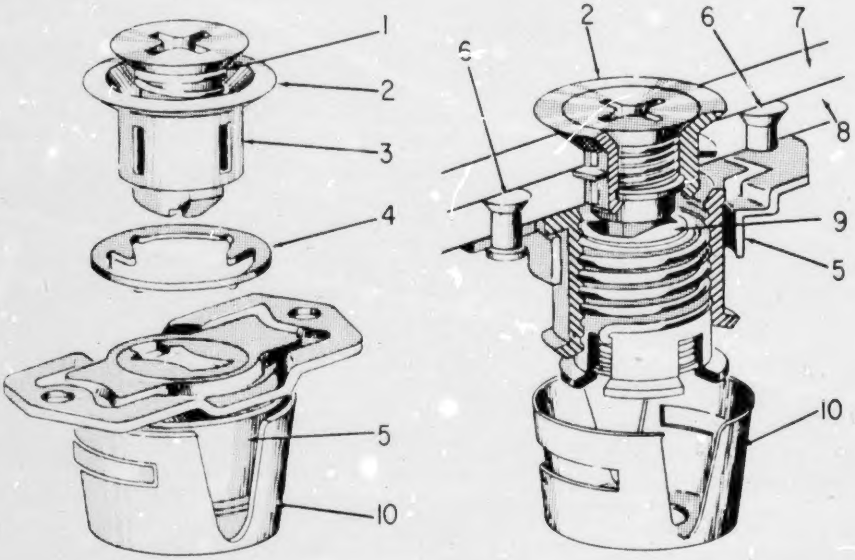
Turnlock fasteners are used to secure inspection plates, doors, and other removable panels on aircraft. Turnlock fasteners are also referred to by such terms as quick-opening, quick-action, and stress panel fasteners. The most desirable feature of these fasteners is that they permit quick and easy removal of access panels for inspection and servicing purposes.

Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the most commonly used are the Camloc stress panel fastener and Airloc, both of which are discussed in this section. Other turnlock fasteners are covered in the Rate Training Manuals Airman, NavPers 10307-C, and Tools And Their Uses, NavPers 10085-B.

Camloc Stress Panel Fasteners

The Camloc stress panel fastener (fig. 4-14) is a high-strength, quick-release, rotary type fastener and may be used on flat or curved, inside or outside panels. The fastener may have either a flush or nonflush stud. The studs are held in the panel with flat or cone-shaped washers, the latter being used with flush fasteners in dimpled holes.

This fastener may be distinguished from screws by the deep No. 2 Phillips recess in the stud head and by the bushing in which the stud is installed. A threaded insert in the receptacle provides an adjustable locking device. As the



AT.85

1. Tension spring.
2. Stud assembly.
3. Bushing.
4. Retaining ring.
5. Receptacle assembly.
6. Receptacle attaching rivets.
7. Outer skin.
8. Inner skin.
9. Insert
10. Cover.

Figure 4-14.–Camloc stress panel fastener.

stud is inserted and turned counterclockwise 1/2 turn or more, it screws out the insert sufficiently to permit the stud key to engage the insert cam when turned clockwise. Rotating the stud clockwise 1/4 turn engages the insert; and continued rotation screws the insert in, tightening the fastener. Turning the stud 1/4 turn counterclockwise will then release the stud but will not screw the insert out far enough to permit reengagement in installation. It is necessary to turn the stud at least 1/2 turn counterclockwise to reset the insert.

To unlock the stress-panel fastener and reset it in the same operation, use a No. 2 Phillips screwdriver, turning the stud counterclockwise 1/2 turn or more. Do not turn the stud past stop.

CAUTION: Do not use a power screwdriver on this fastener.

To lock, use a Phillips No. 2 screwdriver, push the stud in, and turn clockwise until increased torque is felt; then continue turning until the fastener is tight.

NOTE: When installing a large panel, it may be necessary to engage all the fasteners before tightening. This is done by pushing each stud in and turning it clockwise 1/4 turn. The stud should engage the receptacle but remain loose. If the stud does not engage, it will pop out, indicating that the insert must be reset by turning the stud counterclockwise 1/2 turn or more.

Airloc Fastener

The Airloc fastener consists of a stud, stud cross pin, and a receptacle. (See fig. 4-15.) The stud is attached to the access cover, and is held in place by the cross pin. The receptacle is riveted to the access cover frame. A quarter turn of the stud (clockwise) locks the fastener in place; turning the stud counterclockwise, unlocks the fastener.

CONNECTORS

In the discussion which follows, the word "connector" is used in a general sense. It applies equally well to connectors designated by "AN" numbers and those designated by "MS" numbers. AN numbers were formerly used for all supply items cataloged jointly by the Army and

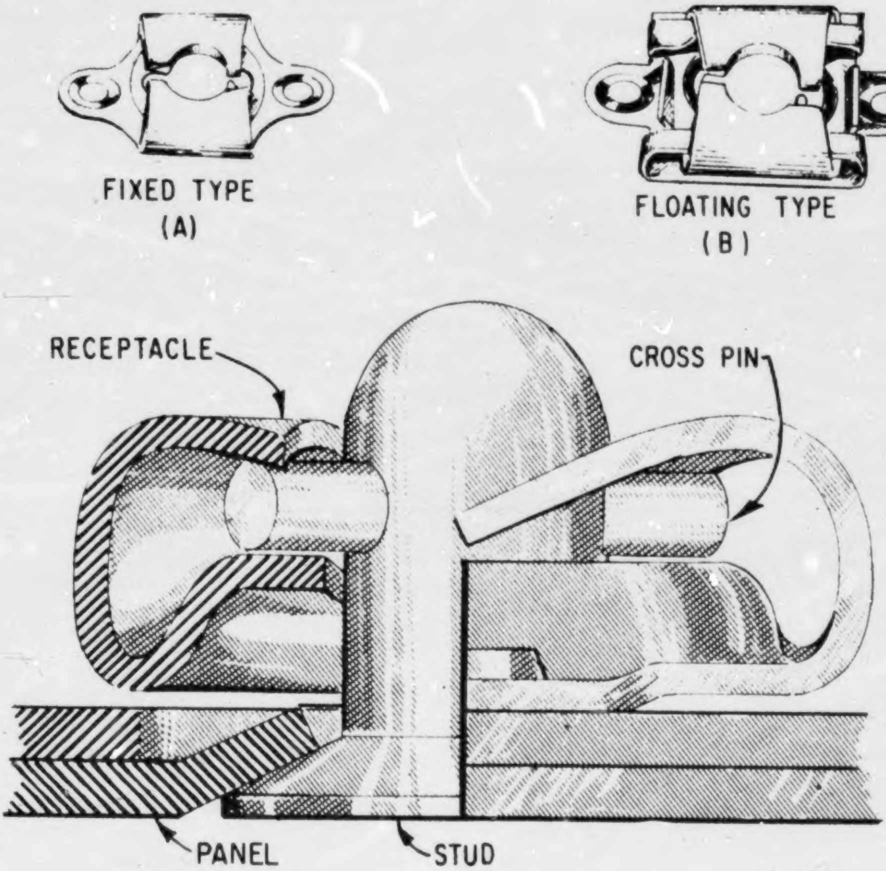


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Figure 4-15.—Airloc fastener.

Navy. Many items, especially those of older design, continue to carry the AN designator, even though the supply system is shifting over to MS (Military Specification) numbers.

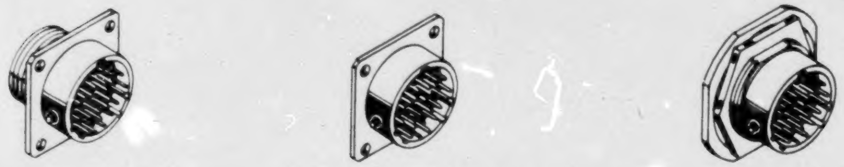
Connector Construction

Electrical connectors are designed to provide a detachable means of coupling between major components of electrical and electronic equipment. These connectors are constructed to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

These connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut, and each consists of an aluminum shell containing an insulating insert which holds the current-carrying contacts. The plug is usually attached to a cable end and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected and is usually mounted on a part of the equipment. When the two parts are joined by the coupling device, the electric circuit is made by pin-and-socket contacts inside the connector. The "live" or "hot" side of the circuit usually has socket (female) contacts. Either the plug or the receptacle may contain the live parts of the circuit. The contacts are held in place and insulated from each other and from the shell by a dielectric insert.

Miniature Connectors

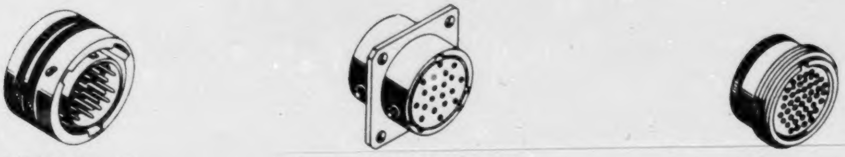
There are wide variations in shell type, design, size, layout of contacts, and style of insert. Six types of connectors are shown in figure 4-16 and described in table 4-2.



WALL MOUNTING RECEPTACLE
SOLDER: MS3110 & MS3130
CRIMP: MS3120 & MS3140

BOX MOUNTING RECEPTACLE
SOLDER: MS3112 & MS3132
CRIMP: MS3122

JAM NUT RECEPTACLE
SOLDER: MS3114 & MS3134
CRIMP: MS3124 & MS3144



STRAIGHT PLUG
SOLDER: MS3116
CRIMP: MS3126

THRU-BULKHEAD RECEPTACLE
SOLDER: MS3119 & MS3139

SHORT PLUG
SOLDER: MS3137
CRIMP: MS3147

AT.2

Figure 4-16.—Miniature connectors MIL-C-26482.

Table 4-2.—Types of miniature MS connectors.

MS Type	Descriptive comparison
MS3110	A receptacle with flange for mounting to a wall or bulkhead; is coupled by means of a bayonet lock; has solder contacts.
MS3130	Similar to MS3110 except that it has push-pull (fall-lock) coupling.
MS3120	Similar to MS3110 except that it has crimp contacts.
MS3140	Similar to MS3130 except that it has crimp contacts.
MS3112	A receptacle for mounting to junction box or equipment case similar to MS3110 except that it has no back shell; has bayonet lock coupling; has solder contacts.
MS3132	Similar to MS3112, except that it has push-pull coupling.
MS3122	Similar to MS3112, except that it has crimp contacts.
MS3114	A single-hole rear-mounting receptacle, with jam nut instead of flange; has bayonet lock coupling; has solder contacts.
MS3134	Similar to MS3114 except that it has push-pull coupling.
MS3124	Similar to MS3114 except that it has crimp contacts.
MS3144	Similar to MS3134 except that it has crimp contacts.
MS3116	A straight plug for use at end of wire bundle; has bayonet lock coupling; has solder contacts.
MS3126	Similar to MS3116 except that it has crimp contacts.
MS3119	A thru-bulkhead mounting receptacle; has bayonet lock coupling; has solder contacts.
MS3139	Similar to MS3119 except that it has push-pull coupling.
MS3137	A straight plug for use at end of wire or wire bundle; has bayonet coupling; has solder contacts.
MS3147	Similar to MS3147 except that it has push-pull coupling and crimp contacts.

There are five classes of miniature MS connectors with solder-type contacts. These are as follows:

Class E—an environment (moisture and vibration) resisting connector, moisture-proofed by means of a wire grommet seal and clamping nut.

Class F—an environment resisting connector, similar to class E, with the addition of a strain relief clamp.

Class H—a hermetic sealed receptacle which has a glass insert fused to the contacts and shell.

Class J—a connector incorporating a gland seal for sealing a jacketed cable.

Class P—connectors supplied with a plastic potting mold, so that the connectors may be sealed by the application of a potting compound.

NOTE: Miniature MS connectors with crimp-type contacts are of the environment resisting classes.

Each MS connector is marked on the shell or coupling ring with a code of letters and numbers giving all the information necessary to identify the connector. This symbol indicates the shell type, the shell class, the size, the insert arrangement, the style of contact, and the insert position. (See fig. 4-17.) An example is the designator MS3114 E 12-10 PW.

The letters MS form the prefix and indicate that the connector has been made according to government standards. The number 3114 indicates the shell type and identifies the connector as one of the types shown in figure 4-16.

The letter E indicates the design of the shell and for what purpose the connector is normally used.

The number 12 indicates that the shell size has an outside diameter three-fourths of an inch.

The number 10 is a designation of the insert arrangement. An explanation of various pin

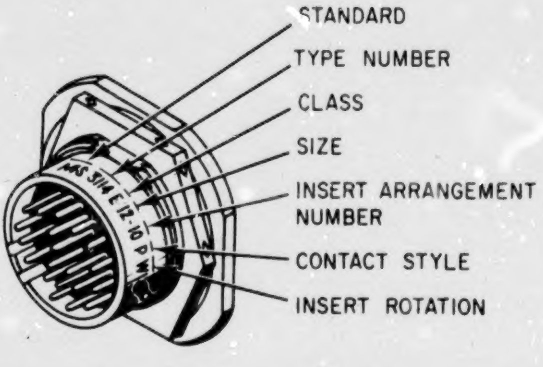

STANDARD
TYPE NUMBER
CLASS
SIZE
INSERT ARRANGEMENT NUMBER
CONTACT STYLE
INSERT ROTATION
MS 3114 E 12-10 P W
AT.3

Figure 4-17.—MS connector marking.

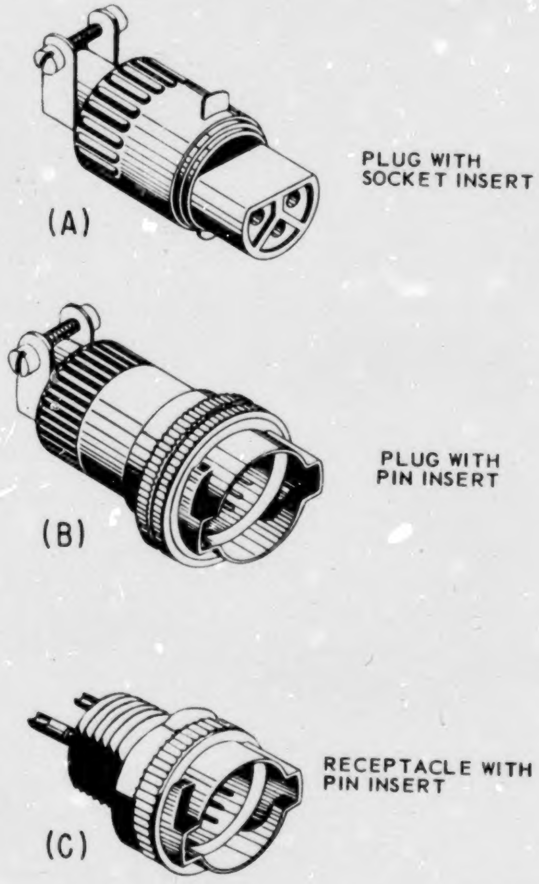

(A)
PLUG WITH SOCKET INSERT
(B)
PLUG WITH PIN INSERT
(C)
RECEPTACLE WITH PIN INSERT
AQ.367

Figure 4-18.—Subminiature connectors. (A) Plug with socket insert; (B) plug with pin insert; (C) receptacle with pin insert.

arrangements may be found in the manual, Installation Practices for Aircraft Electric and Electronic Wiring (NA 01-1A-505).

The letter P means that the insert is a pin or male insert. (The letter S is used to indicate a socket or female insert.)

The concluding letter W is a designation of the insert position. Connectors specially designed for a particular application sometimes have nonstandard contact or insert positions. Four positions of the inserts are employed, and these are W, X, Y, and Z. Each letter refers to an angle by which the insert is rotated from the standard position. When the standard position is employed, no letter is shown at the end of the MS designation.

Subminiature Connectors

Three common types of subminiature connectors are shown in figure 4-18. Since these connectors are the wire-connected type, they have no flanges for mounting. However, the receptacle shown in part (C) can be mounted with nuts and lockwashers. They are used on miniature instruments, switches, transformers, amplifiers, and relays.

Coaxial Connectors

Coaxial connectors are divided into several different series and are shown in figure 4-19. Each series consists of plugs, panel jacks, receptacles, and straight and right angle adapters.

Series UHF connectors are low-cost, general purpose connectors of nonconstant impedance. The small and large coaxial types are for use

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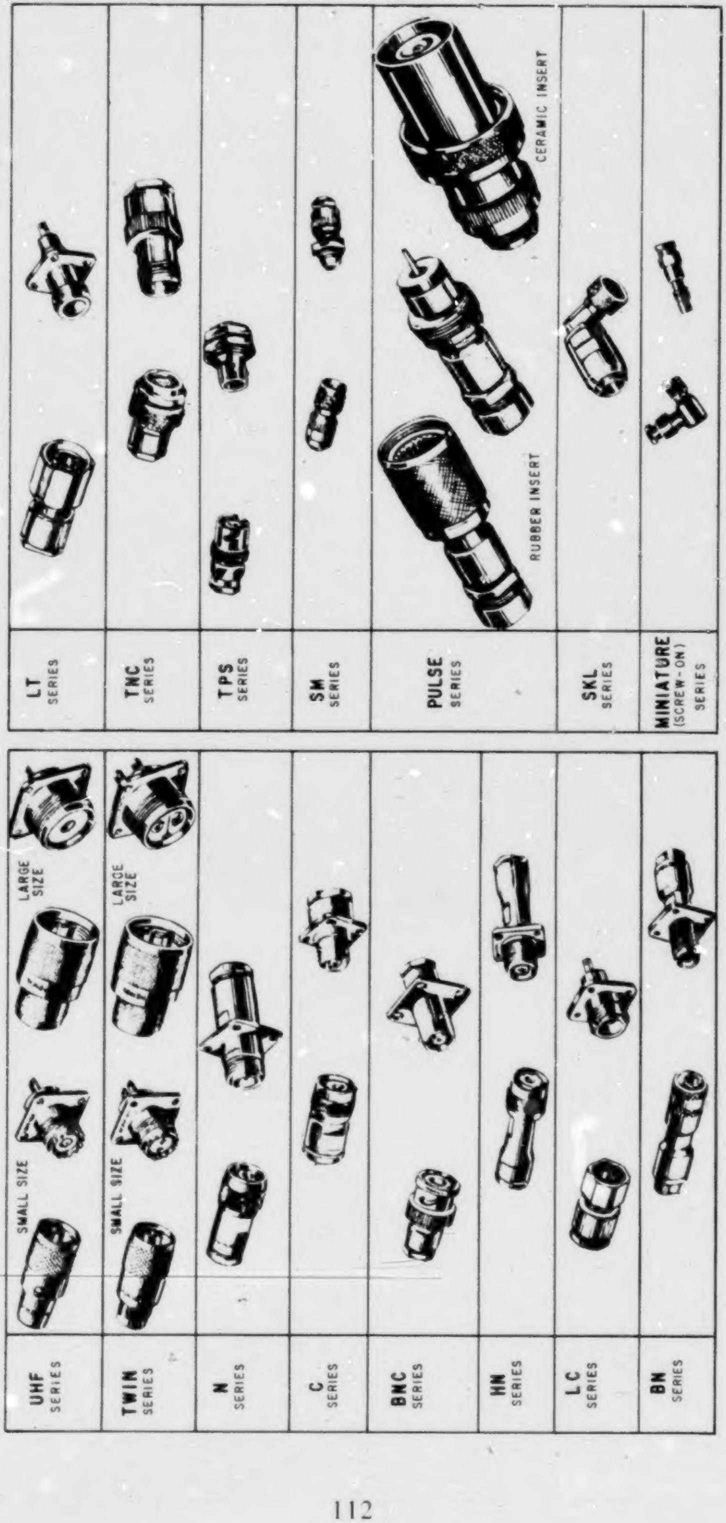

LT SERIES
TNC SERIES
TPS SERIES
SM SERIES
PULSE SERIES
RUBBER INSERT
CERAMIC INSERT
SKL SERIES
MINIATURE (SCREW-ON) SERIES
UHF SERIES
SMALL SIZE
LARGE SIZE
TWIN SERIES
SMALL SIZE
LARGE SIZE
N SERIES
C SERIES
BNC SERIES
HN SERIES
LC SERIES
BN SERIES
AQ.368

Figure 4-19.—Several typical coaxial connectors.

with small and medium size coaxial cables in applications where line imbalance or increased standing wave ratio is not important. Where impedance matching is necessary, C, N, or BNC series connectors are used. Both small and large series UHF connectors can be weatherproofed for outdoor use but most are nonweatherproof.

The twin connectors are similar to the series UHF connectors except for the fact that they have twin center conductors and are to be used with small and medium sized twin-conductor cables. Twin connectors are available in small weatherproof and nonweatherproof types and large nonweatherproof types.

Series N connectors are the most popular constant impedance connectors for medium size coaxial cables. They can be used up through microwave frequencies with minimum line imbalance or increase in standing-wave ratio. Although series N 50-ohm and 70-ohm connectors do not mate, 70-ohm cables may be used with 50-ohm series N connectors where impedance matching is not critical. Series N connectors are completely weatherproof.

Series C connectors are similar to 50-ohm series N connectors in that they are used with the same cables, are weatherproof, and can be used up through microwave frequencies. However, they are mechanically and electrically superior to series N connectors. Series C connectors feature bayonet-lock type coupling for quick connect and disconnect, an improved cable clamping mechanism for better cable grip with minimum cable indentation, and are intended for use up to 1,000 volts.

Series BNC connectors (fig. 4-20) are commonly used on small coaxial cables. All incorporate quick connect and disconnect bayonet-lock coupling and are weatherproof. Besides regular and modified low-voltage types of nonconstant impedance, improved series BNC connectors are available which have a constant 50-ohm impedance and yield excellent electrical performance up to 10,000 megahertz.

Series HN connectors are weatherproof high-voltage connectors of constant impedance for use with 50-ohm RF cables.

Series LC connectors are large, 50-ohm, weatherproof connectors designed for applications involving the transmission of large amounts of RF power.

Series BN connectors are small, lightweight connectors (of non-constant impedance) designed for use with the same coaxial cables which use BNC connectors. BN connectors are not recommended for applications at frequencies in excess of 200 megahertz unless electrical requirements of the circuit are not critical. They may be used at peak voltages up to 250 volts.

Series LT connectors are very similar in appearance to series LC; however, series LT

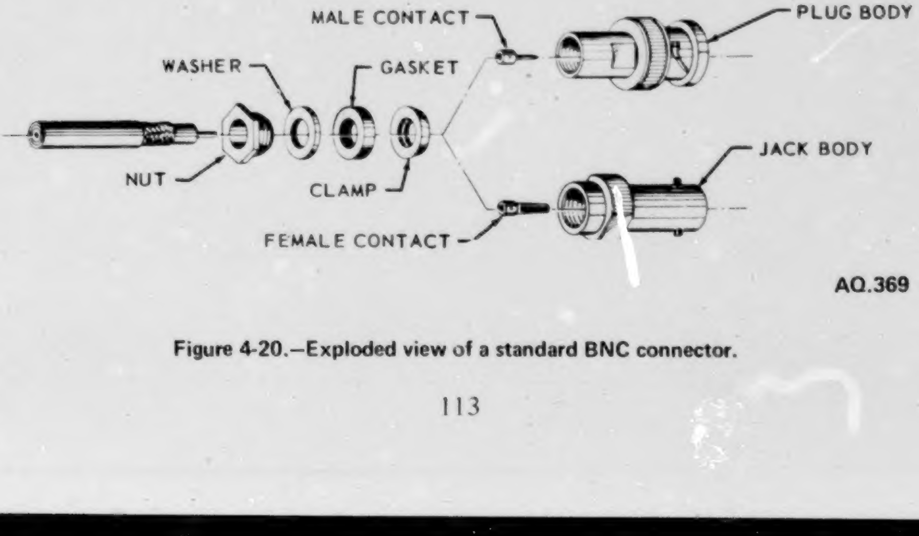


Figure 4-20.—Exploded view of a standard BNC connector.

differ not only in cable accommodation but are lighter than series LC connectors. Series LT connectors are large, 50-ohm, 5,000-volt connectors for use with Teflon RG-117/U cable.

Series TNC connectors are basically identical with series BNC connectors. The major difference is that TNC connectors have a threaded type coupling instead of the bayonet-lock coupling. Consequently, TNC connectors are usually preferred in applications which are subject to extreme vibration.

Series TPS connectors are weatherproof and designed to produce minimum electrical discontinuities in small size 50-ohm coaxial cable up to a frequency of 10,000 megahertz. The connectors are rated at 1,500 volts rms at sea level; their use is governed by the temperature limitations of their associated cables.

Series SM connectors are nonweatherproof fittings for coaxial cables of 1/4-inch overall diameter and smaller. They may be used where electrical matching is not required. The SM connectors are smaller and contain fewer parts than the BNC series. The SM series employs a female center-conductor contact on plugs and a male center-conductor contact on jacks and receptacles. However, for consistency in cataloging and usage, a plug is still regarded as having a male mating end and a receptacle or jack as female. The SM series is not intended to replace the BNC series except for internal equipment connections where weatherproofness is required.

The pulse connectors are designed for high-voltage pulse or direct-current applications. They are nearly all weatherproof and available in three types—rubber-insert, ceramic-insert, triaxial. The rubber-insert type PULSE connectors have a peak voltage rating of 5,000 volts at an altitude of 50,000 feet. They are designed principally for use with cables having an insulated Neoprene layer under the braid, such as RG-77/U and -78/U.

They may be used with cables employing a conducting rubber under the braid (such as RG-25/U, -26/U, and -64/U) provided special care is taken in assembling the connectors to these. The ceramic-insert pulse connectors are available in small (type A) and large (type B) sizes. Type A connectors are designed for use with the 8,000-volt RG-25/U, -26/U and type B with the 15,000-volt RG-27/U, -28/U cables. (Special care is required when assembling connectors to these.) Pulse connectors tend to leak noise which may interfere with communications equipment. Triaxial connectors are used in transmission line applications where maximum RF shielding and minimum noise radiation are required. They are commercially available in sizes of the same diameter as the BNC series and C series (and possibly others). Some of these connectors have been used in military equipment and some within-series adapters are commercially available.

The SKL connectors were originally designed to provide a connection to a klystron tube. Newer klystrons are being equipped with BNC connectors. Various modifications were subsequently designed to provide general purpose cable-to-cable connections and adapters.

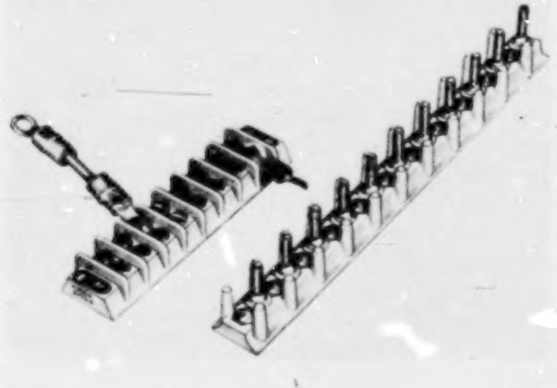
Miniature connectors have a gold finish, screw type coupling, and Teflon dielectric. They have a nominal impedance of 50 ohms, a sea-level breakdown voltage of 1,500 volts rms, a practical frequency limit of 10,000 megahertz, and are designed for operation up to 200°C.

Terminal Junction Systems

A new method of terminating and distributing electrical power—either in an entire weapons system or in individual items of electronic equipment—is now replacing the problem-ridden terminal board that has been used in the electrical systems of aircraft, missiles, and ground power equipment. Essentially, the components comprising the terminal junction system (TJS) are pin contacts, modules, splices, and tracks. The tracks are the holding members for the modules.

Terminal boards (see fig. 4-21) are heavy, bulky and, because of their open construction, easily contaminated by moisture, dust, and fluids from their environment. In addition, their open construction makes them susceptible to electrical short circuits caused by metallic objects inadvertently dropped on them. To overcome these drawbacks the terminal junction system was designed.

The environment-proof modules which form the heart of the TJS are mounted in tracks and provide a higher concentration of contacts or terminations, lighter weight per contact, greater



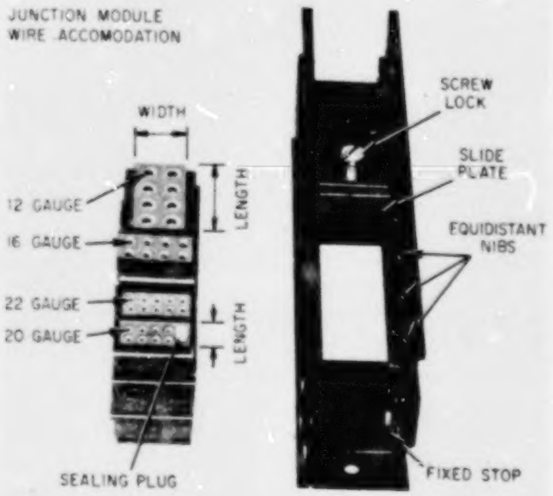
AT.4

Figure 4-21.—Terminal boards.

distribution flexibility, and easier access for checkout of the system by the technician. The modules are available with a wide variety of contact arrangements. The components of the system are used for interconnecting components and equipment in electrical and electronic systems. They are presently being used in some helicopters, the F-4 and F-14A aircraft, as well as the Sentinel Antiballistic Missile System and the Apollo Launch and Tracking Systems.

The principal items of the terminal junction system are (1) modules containing a number of socket contacts for the reception of wired pin contacts and, (2) separate tracks in which a variety of the modules may be mounted and securely held. (See figure 4-22.) The flexible system accommodates any number of wire connections from various components by the addition of extra modules and tracks as needed. Modules containing size 22, 20, 16, or 12 contacts are available.

The compact, lightweight terminal junction system is extremely useful in aircraft electronic systems. Simply and speedily installed, the flexible modules terminate or act as distribution points for a broad range of wire sizes. Because the procedures and tooling are similar to those for the the crimped connector contacts, the technician has no need to carry screwdrivers or special box wrenches to the termination job.



(A) BLOCKS (B) TRACK

AT.5

Figure 4-22.—Feedthrough modules and track.

Installation and removal of the pin contacts are accomplished through the use of the applicable-size insertion-extraction tools available in the naval supply system.

WIRE

Although modern technical literature has been emphasizing the use of printed circuits and microelectronic components in contemporary electronic equipment, wire is still important as a signal or current carrying device. Therefore wire does deserve appropriate attention.

Since most naval equipment is of conventional construction, and complete conversion to the new forms of conducting components is not yet imminent, traditional wire conductors are in use, and probably will continue to be in use for some time to come. This means that when wire is to be requisitioned, either for installation or repair, care must be exercised in its selection. The three major factors involved in this selection, in descending order of importance, are size, insulation, and the characteristics required to satisfy specific environments in which the wire must function. Wire is discussed in detail in Basic Electricity, NavPers 10086-B.

Conductor Size

For d-c applications, the allowable voltage drop and current-carrying capacity govern the choice of size. At radio frequencies, the skin effect and inductance may become a controlling factor, although generally (except in inductors or RF transformers) these parameters need not be considered. Wire size is therefore basically a function of the current or the allowable resistance, except when this results in a very small conductor size.

Small conductors are difficult to handle and are subject to breakage in soldering or due to vibration. Experience has shown that these difficulties may be avoided by using No. 22 or No. 24 AWG for general circuit wiring and at least No. 20 AWG for parallel connected tube filaments. Solid wire should be used only for short jumper connections not exceeding 3 inches in length, unless the parts being connected are solidly mounted and not subject to vibration. Clamps or "dress lugs" are recommended for long leads. In other words, the use of stranded copper wire whenever possible is strongly recommended, although under extreme conditions of vibration or where high flexibility is required, oxygen-free copper is sometimes specified. Copperclad steel is another possibility for applications requiring greater strength and rigidity.

Insulation

A wide variety of insulating material is available, which makes its specification particularly important. Since each insulation has its peculiar characteristics, no single type is therefore always suitable for general usage. The major insulation requirements include good dielectric strength, high insulation resistance (internal and surface), wide temperature range (with high softening and low brittle points), flexibility, color stability, and resistance to abrasion, crushing, moisture, fungus, burning, radiation, oil, and acids.

Insulation requirements for electronic, as opposed to power, applications are somewhat more exacting due to the higher frequencies and impedances and often higher voltages involved. Insulation resistance and dielectric strength are the prime considerations, although for RF application the figure of merit (capacity to Q ratio) becomes important.

Some of the insulations used for general hookup wire include lacquered cotton, high temperature rubber, butadiene styrene copolymers, Celanese, Fiberglas, nylon, vinyl, polyvinyl-chloride, cellulose acetate, polystyrene, polyethylene, Teflon, and various silicon-treated materials. An insulation wall thickness of not less than 0.013 inch is recommended for all wiring within the confines of an enclosure or where mechanical protection is provided. Where wiring is exposed or subject to wear or abrasion, heavier insulation is required.

Environments

Environmental factors such as temperature, humidity, altitude, vibration, radiation, fungus, contaminants, and corrosive elements must be taken into consideration. These requirements are included as a part of the specification for the equipment where the wire is to be used.

Wire Identification

Wiring in aircraft normally runs from point to point, or plug to plug, without interruption (no splices). However, there are acceptable methods of making permanent splices.

Wiring in aircraft is identified by a system of numbers and letters stamped on each wire as described in chapter 2 of this manual. The Maintenance Instructions Manual gives the number of each wire involved in cabling of electronic equipment. Should it become necessary to trace and repair a wire in the aircraft, refer to this manual to determine the routing of the wire involved.

Wiring data for all electrical and electronic systems in each model aircraft are contained in the Wiring Data section of the applicable Maintenance Instructions Manual. The diagrams are prepared separately for each circuit and provide all data necessary to understand the construction of each circuit, to trace each circuit within the system, to make continuity and resistance checks, and to perform specific troubleshooting on inoperative or malfunctioning circuits. Schematic diagrams for circuits and related components are found in those volumes of the Maintenance Instructions Manuals specifically covering a system or systems.

An excellent source of information in connection with power distribution and aircraft wiring is Installation Practices for Aircraft Electric and Electronic Wiring, NA 01-1A-505. This manual presents the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring.

COAXIAL CABLES

Flexible coaxial cables (sometimes called RF cables) are a special type of cable used for carrying video and RF signals, cathode-ray-tube sweep currents and voltages, trigger range marks, blanking pulses, and other signals for radar receivers, transmitters, and indicators. These cables are constructed with special considerations for shielding, impedance, capacitance, and attenuation. All of these factors are of importance in many circuits. Coaxial cables have neither induction nor radiation losses. These lines have low attenuation even at very high frequencies and are used as high as 3000 MHz.

The name coaxial is derived from the construction, in that the inner and outer conductors have a common axis or coaxis. These cables consist of an inner conductor, a dielectric insulator, an outer conductor, and an outer covering. The inner conductor is usually made of copper—plain, tinned, or silver coated. The dielectric insulation is usually polyethylene, although other materials are used. The outer conductor is made of a single or double braid of plain, tinned, or silver-coated copper. The outer covering is made of a synthetic resin (vinyl), Teflon tape, or chloroprene. This covering serves both as weatherproofing and protection from mechanical abuse.

Flexible coaxial cables are classified in four groups; namely, general purpose, high temperature, pulse, and special characteristics. The general purpose cables consist of various sizes of cables as just described. The high temperature cable is basically the same but usually has a dielectric made of Teflon, and the outer covering is made of Teflon tape and fiberglass braid which enables it to withstand increased temperatures. Pulse cables have the ability to withstand high voltages because of conductor spacing and the type of dielectric used in their construction.

The special characteristics cables are made of various materials and sizes of inner conductor, outer conductor, dielectric, and outer covering. By varying these parts, the capacitance, impedance, shielding, attenuation, voltage rating, and the ability to withstand weather and abuse are varied to fit the required qualities. With exception of the special characteristics type, these coaxial cables have an impedance of 50 to 75 ohms. The impedance of the special characteristics type is often much higher. An example is the RG-65A/U which has an approximate impedance of 950 ohms and is used as a high impedance video cable. In replacing a coaxial cable, care should be exercised to use the correct replacement, otherwise most of the advantages of coaxial cables are lost.

At frequencies near 3000 MHz, flexible coaxial cables have appreciable losses. At these frequencies, rigid coaxial cables are used with air as the dielectric. The inner conductor is supported by ceramic or polystyrene beads.

POTTING COMPOUND

Most electrical connectors and some relays used in aircraft are potted to prevent corrosion, contamination, or arc-over between pins and terminals. Because of temperature variations throughout the aircraft, two different potting compounds are used—one is tan and the other red. The temperature range of the potting compound can be determined from its color. The tan compound is used where the temperature under operating conditions does not exceed 87.8°C (190°F). The red compound is used where the temperature is higher. Should it become necessary to replace or repot a relay or connector, the potting compound used should have the same temperature range (color) as the original material. Care should also be taken to duplicate the shape of the original potting so that no installation problems will occur.

Potting Procedures

At times, operating conditions demand that ordinary electrical connectors be given a moistureproofing treatment. The basis of moistureproofing is the application of a sealing compound.

Moistureproofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by vibration and lateral pressure, both of which fatigue the wire at the solder cup.

The sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved dielectric characteristics, it reduces the possibility of arc-over between pins at the back of electric connectors.

The sealant is provided in kit form through the normal supply channels. Sealing (or potting, as it is called) is not required on environment-proof E connectors or connectors located in areas where the temperature exceeds 200°F. The sealing compound deteriorates after long exposure to ambient temperature above 200°F.

A summary of the procedures involved in sealing a connector is as follows:

1. Prepare a used connector by removing existing sealants and by cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections and add a length of wire approximately 9 inches long to each unused pin. Remove any excess rosin from around the pins and the insert; a stiff bristle brush is helpful in doing this. Now, repeat the cleaning, and then separate the wires evenly.

2. Thoroughly mix the accelerator and base compound (fig. 4-23). The ratio of the amount of accelerator to the amount of base compound is critical; therefore, the entire quantity of accelerator furnished must be added to the base compound.

3. Place the plugs or receptacles on a table, arranging them so that gravity will draw the sealer to the bottom of the plug. Box receptacles or plugs without back shells must be fitted with a mold made of masking tape or cellophane tape or equivalent. (See (a) of fig. 4-24.) This will retain the sealant during the curing process. If the back shell is used, apply a slight amount of oil to the inner surfaces to prevent the compound from adhering to it.

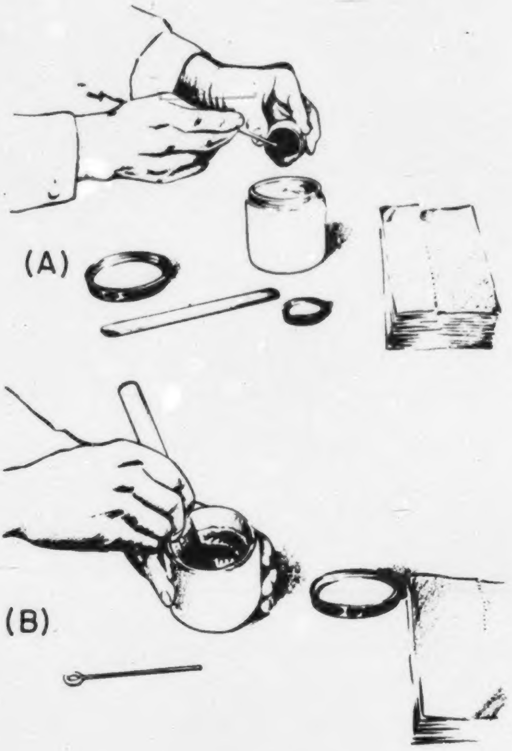


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Figure 4-23.—Combining accelerator with base compound.

4. The compound is applied by a spatula, putty knife, or paddle. It should be packed around the base of the pins. The part being potted should be completely filled or at least to a point to cover 3/8 inch of insulated wire. The compound is now allowed to cure; temperature will affect the curing time. The normal curing time is approximately 24 hours.

If it is desired that the entire connector assembly (plug and receptacle) be sealed against fluid entering or collecting between the two

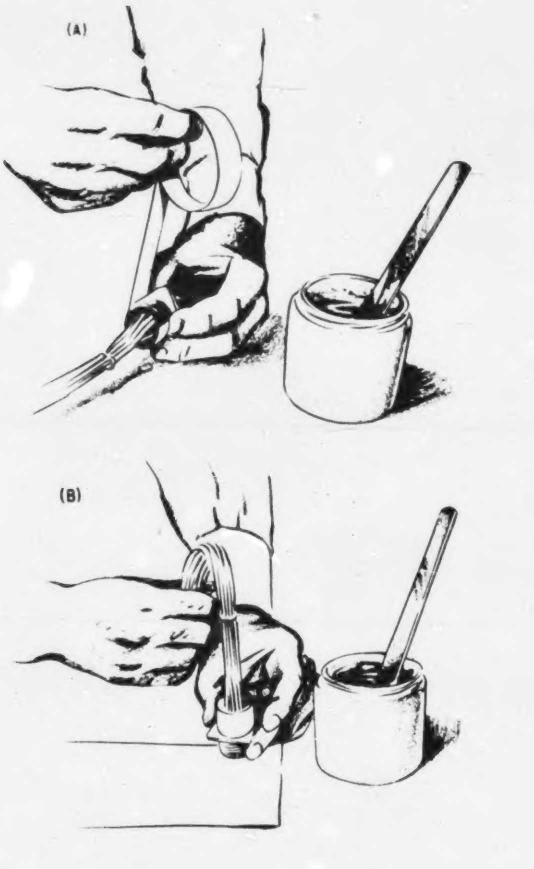

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Figure 4-24.—(A) Making mold from masking tape; (B) finished potted plug.

parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug. This will provide a seal when the two parts are engaged securely. If properly installed, this seal will prevent moist air from entering due to variations in temperature, altitude, or barometric pressure on the ground. Rubber packing O-rings are available for this purpose through normal supply channels. Due to the aging of these rings in service, it is necessary to examine them each time the connector is disassembled. If deteriorated, they must be replaced.

The purpose of soldering a short length of wire to each spare pin is to allow for growth requiring additional circuits to be included in the connector.

FUSES

Fuses provide a controlled, intentionally weakened link in an electric circuit and serve as safety devices in the event of undesired overloads. They are available with ratings of from 2 milliamperes to several hundred amperes—most ratings being available for normal, slow-action or fast-action operation. Basic Electricity, NavPers 10086-B, describes fuses in detail.

Identification Coding

Fuses and their corresponding fuse holders are numbered according to a standardized system for easy identification. The numbering system is illustrated and explained in figure 4-25; some actual fuses are shown in figure 4-26.

ACCOUNTABILITY

A definition of the word accountability is "the state or quality of being responsible—a charge (object) for which one is responsible or accountable." The Navy has a code that is called Material Accountability Recoverability Codes (MARC's). These codes appear in column 3 of the Section G Allowance List, NA 00-35QG-0 Series and are illustrated by the following examples:

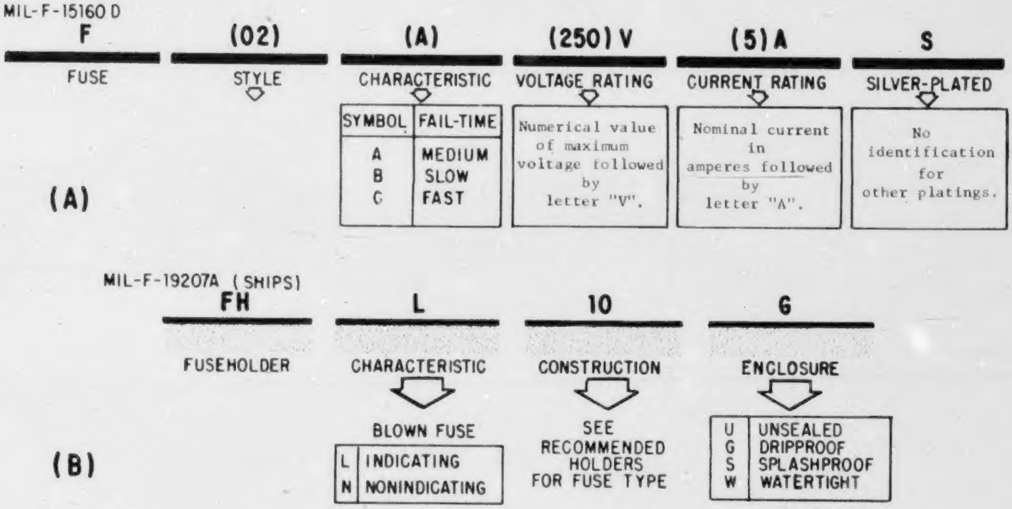
Code:

B—Exchange consumables—requiring old items for replacement items such as items containing precious metal, highly pilferable items, or certain high cost items. Example: Drill, electric portable, FSN 9Q 5130-226-5384.

C—Consumables—expendables. Example: Stripper, Wire, FSN 9Q 5110-268-4220.

CUSTODIAL RESPONSIBILITY

Most handtools are not feasibly repairable. Due to this fact and their original low cost (compared to shop tools), they are classed as


MIL-F-15160 D
F
FUSE
(02)
STYLE
(A)
CHARACTERISTIC
SYMBOL
FAIL-TIME
A MEDIUM
B SLOW
C FAST
(250) V
VOLTAGE RATING
Numerical value of maximum voltage followed by letter "V".
(5) A
CURRENT RATING
Nominal current in amperes followed by letter "A".
S
SILVER-PLATED
No identification for other platings.
(A)
MIL-F-19207A (SHIPS)
FH
FUSEHOLDER
L
CHARACTERISTIC
BLOWN FUSE
L INDICATING
N NONINDICATING
10
CONSTRUCTION
SEE RECOMMENDED HOLDERS FOR FUSE TYPE
G
ENCLOSURE
U UNSEALED
G DRIPPROOF
S SPLASHPROOF
W WATERTIGHT
(B)

AT.49

Figure 4-25.—Identification coding. (A) Fuse; (B) fuse holders.

consumable. However, the activity must pay for replacements. Therefore, it is the duty of each individual to help eliminate the need for replacements. One method of accomplishing this is by carrying an inventory of tools in your toolbox so that upon completion of a job you can be sure that all of the tools are accounted for. A tool that has been lost represents a waste of funds; in addition, it is a definite liability. If it has been left loose in an aircarft, it can become a dangerous missile when the aircraft is launched or when the aircraft is performing violent maneuvers.

Inventory Requirements

The basic objective of an inventory is to insure a proper balance between the supply of, and the demand for, those tools required for the efficient operation and maintenance of a squadron or maintenance activity. To accomplish this objective it is necessary that tools be identified and cataloged to provide accurate knowledge of the tools being used. Each item should be accounted for every 30 to 90 days in accordance with squadron instructions. The number of handtools on hand in relation to the number required by the activity should be indicated by the inventory.

Reordering Tools

Tools are reordered as the inventory requirements dictate. Usually the senior petty officer or his delegate reorders all tools—both shop tools and those for individual toolboxes, as they are needed. However, squadron or maintenance activity policy is followed in all cases.

It is unwise to wait until the number of tools needed is too large, as it is easier for the supply department to fill a small order rather than a large one.

Tools are ordered by reference to Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NA 00-35QG-016.

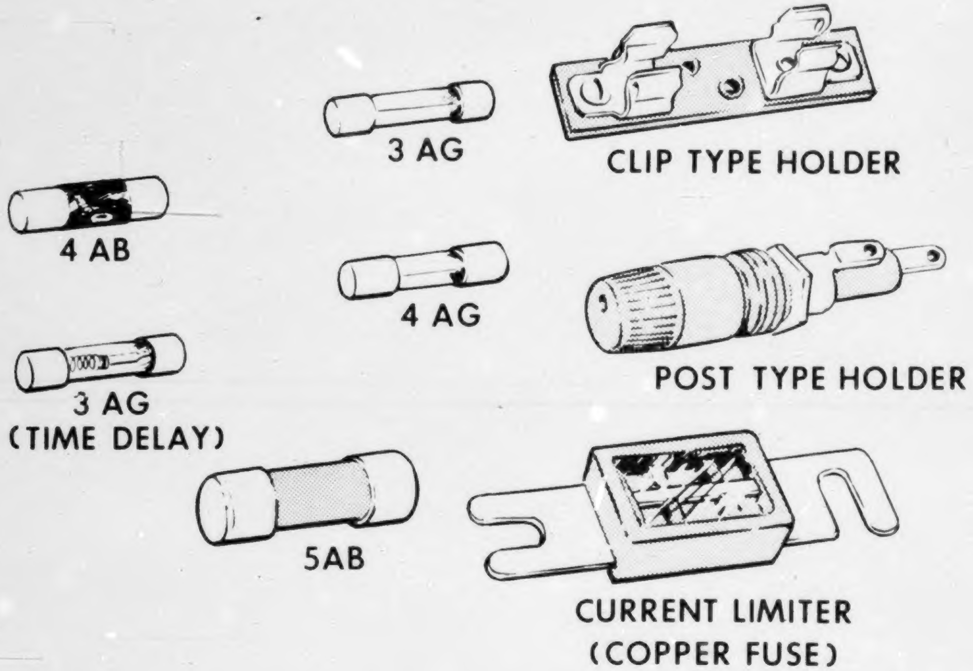


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Figure 4-26.–Aircraft fuses and fuse holders, typical examples.

MATERIAL REQUISITIONING

Maintenance personnel are likely to encounter a variety of local requisitioning channels, all designed to present a demand for an item to the supporting supply department. Assigned levels of maintenance, geographical location of shops relative to supply facilities, and mission of activities requiring support all influence the local requisitioning channels. Local instructions normally promulgate detailed procedures for submitting your demand to the appropriate supply point.

Supply Activity

The mission of the supply activity is to support the operational and maintenance efforts of the activity or ship. Stocks of aviation oriented material carried are tailored and replenished to this end. Positioning, replenishment, and control of stocks of material in maintenance areas are carried out as a result of joint decisions by the supply and maintenance officers concerned. They determine the range, depth, and related procedures. The cost of material used in maintenance is totaled so that the costs of maintaining a weapons system can be determined. This data is used as an inventory management tool to determine geographic and strategic distribution of stocks of material.

SUPPLY SUPPORT CENTER

Maintenance organizations have one single point of contact with the supporting supply activity. This single supply contact point is the Supply Support Center (SSC) which responds to all material requirements of the maintenance organizations. The SSC is an internal organization of the local supply activity. It is made up of two sections–the Supply Response Section (SRS), and the Component Control Section (CCS).

Supply support is available consistent with the operating hours of the maintenance activities supported. If maintenance is being performed 24 hours a day, then supply support is available 24 hours a day.

The supply support center maintains rotatable pool material which consists of repairable ready-for-issue items reserved primarily to satisfy the requirements of organizational level maintenance. Items maintained in the pool are capable of being repaired by the local intermediate maintenance activity, have application relationship to weapon systems supported by local intermediate maintenance activities, and have an average organizational maintenance level removal rate of at least one per month. Defective components are turned in to intermediate level maintenance for repair. The defective components repaired to an RFI condition are then returned to the rotatable pool to replace the components previously issued.

Low value, fast moving consumable items are preexpended from supply. Such materials are located in the maintenance area. The establishment, maintenance, and replenishment of preexpended bins are the responsibility of the supply organization.

Supply Response Section

The Supply Response Section (SRS) is responsible for preparing all necessary requisitions (DD Form 1348) and related documents required to obtain material for local maintenance use in direct support of weapon system maintenance. The maintenance organization verbally notifies the supply organization of the need for such material. When material is available locally, the time frame for processing and delivery is as follows:

Priority	Process/Delivery Time
1-3	1 hour
4-8	2 hours
9-20	24 hours

Otherwise, the time frames as noted in table 4-3 will apply.

The SRS is responsible for receipt, storage, and issuance of all ready-for-issue pool components. It is responsible for physical delivery of RFI material to maintenance organizations, and the pickup of defective components from the organizational maintenance activity and subsequent delivery to the intermediate maintenance activity. Actual maintenance personnel are not involved in the physical movement of material between organizations.

This section also performs technical research in regard to completion of requisition documents as well as determining the status of outstanding requisitions and relaying this status to the customer upon request.

Component Control Section

The Component Control Section (CCS) accounts for all components being processed in the intermediate maintenance activities. This section also records on the status of all rotatable pool components.

TOOL KITS, SHOP TOOLS, AND TOOL CRIBS

One of the first steps taken when a new man reports for duty to the avionics shop of a squadron or activity is to issue him an individual toolbox. The toolbox should contain the low-cost, high-usage handtools that will enable him to perform the tasks assigned. The purpose of the individual handtool kit is to make the necessary tools for performance of line and/or hangar maintenance immediately available to the individual. The contents of the individual handtool kit are among the tools listed in Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NA 00-35QG-016.

Under the crew leader concept of maintenance, the crew leader's kit has the same type tools as the individual handtool kit. It is issued to an individual of a crew and is to be used by all members of that crew. Thus, the crew leader's handtool kit will have several of the same type and/or size tool where the individual kit has only one.

Table 4-3.–Processing time frames.

Issue Group	Issue Priority Designator Range	Supply Source Processing	CONUS On Station Time	Overseas On Station Time
1	1-3	24 hours 24-hour day 7-day workweek	120 hours	168 hours
2	4-8	72 hours 24-hour day 7-day workweek	8 days	15 days
3	9-15	10 days 8-hour day 5-day workweek	20 days	45 days
4	16-20	12 days 8-hour day 5-day workweek	30 days	60 days

Shop tools are the larger, low-usage, and special tools for use on specific equipments. A shop tool bin is normally utilized to make available to the technician those special tools and medium-usage tools needed to perform the various phases of shop maintenance. However, shop tools also include any handtools required to perform more extensive maintenance than can be accomplished from a toolbox or a crew leader's kit. To determine the types and number of shop tools allowed, refer to the applicable allowance list from the NA 00-35QG-0 series.

Frequently a squadron toolcrib has the responsibility for all tools in the squadron, including issuance of tools, inventory of toolboxes, and ordering new tools for replacement of broken or lost tools. A squadron toolcrib is set up under the responsibility of the maintenance department. Its purpose is for the stowage and issuance of low-usage handtools and those which are common to more than one shop. Special tools provided by the aircraft manufacturer are also stowed in the toolcrib. A complete list of these special tools can be found in the Maintenance Instructions Manual, section one, for each type aircraft.

The tools used in an aircraft maintenance activity are determined by the mission of the activity and the type aircraft to be maintained. In view of this, there is no hard and fast rule as to the type and/or number of tools that may be supplied in the different handtool kits and cribs. The quantity and types of tools allowed for an activity may be found in the appropriate allowance list.

CHAPTER 5

AVIONICS SUPPORT EQUIPMENT

Other chapters of this manual discuss the basic principles and concepts of some of the equipment which the technician may encounter. An understanding of the theory of operation of these equipments forms only a portion of the knowledge necessary to successfully perform the maintenance tasks required. A thorough knowledge of electrical and electronic test equipment (often referred to as avionics support equipment) is also needed.

All electronic test equipment is designed and constructed to perform tests of one or more specific types. These tests are used to determine the proper operation or alinement of electronic sets, circuits, or parts. The performance of aircraft electronic equipments is determined by the accuracy of the test equipment used to calibrate and aline them and the care with which the technician performs these jobs. Without test equipment very few electronic devices could be used; therefore, it follows that every technician should learn to use test equipment properly.

The test equipments discussed in this chapter are typical of the ones currently in use in the fleet. No attempt is made to include theory beyond that necessary to describe the operation of the test set under discussion. Whenever the technician must use a piece of test equipment with which he is not familiar, he should always consult the appropriate instruction manual. These publications contain detailed and specific information on the particular equipment. The purpose of this chapter is to discuss some of the different test equipments from the standpoints of operation and general operational and maintenance procedures.

CARE AND USE OF AVIONICS SUPPORT EQUIPMENT

All electronic maintenance shops are provided with a variety of test equipment to be used in maintaining the many different types of electronic units they support. However, there are very few spare test sets. When a test set becomes inoperative, shop maintenance suffers. Therefore, every man must use the test equipment only for the purposes and in the manner for which it was designed. Protect the equipment from physical harm that may result from dropping, falling, or any other careless misuse, and always observe proper operating techniques.

One of the chief causes of test set failure is carelessness. The user can be careless in operating procedure or in handling the set. The usual carelessness in operating procedure is improper selection of range for the quantity to be measured, such as attempting to measure 250 volts on the 50-volt scale of a meter. If there is any doubt about proper usage of a test set, it is wise to refer to the manual issued with the set.

Much damage to test equipment results from improper handling. Technicians often place test sets near the edge of the bench where they can easily be knocked off or pulled off by the test leads. Read the instructions for proper handling and operating procedure, and think while using the equipment.

CALIBRATION

Calibration is the process of comparing a device used for measuring with a standard. Whether the device is a foot rule, a clock, a scale, a voltmeter, or any of the numerous devices used for measuring, somewhere there must exist a standard for each value to be measured. This standard must be as accurate as possible, and it must be widely recognized as the most accurate measurement of that particular unit.

The National Bureau of Standards provides standards and standards services for the Nation. The Navy avails itself of these services through the Navy calibration program. The Navy calibration program establishes a liaison between the test and measuring devices used by fleet and contractor personnel and the reference standards maintained by the National Bureau of Standards.

Three factors that limit the accuracy of any measurement are as follows:

1. The ability of the observer.
2. The environment in which the measurement is performed (temperature, humidity, cleanliness, vibration, etc.).
3. The accuracy and precision of the test and measuring instruments used. Each of these limiting factors can be controlled to some extent. The ability of the observer is developed through training and experience, and evaluated by examination. The environment is controlled by air-conditioning systems, air filters, vibration isolators, etc. The accuracy and precision of the test and measuring instruments are controlled by calibration.

REPAIR

When calibration is not involved, minor repair of test sets is often accomplished at the Organizational level of maintenance. Repairs are usually limited to replacement of test leads and fuses. Current instructions on repair of test equipment should be consulted before attempting any repairs of a major nature.

HANDLING PRECAUTIONS

Some equipments may require special handling; however, there are several precautions which apply to test equipments in general. Rough handling, moisture, and dust all affect the useful life of such devices. Bumping or dropping a test instrument, for example, may destroy the calibration of a meter or short circuit the elements of an electronic tube within the instrument. Creasing or denting coaxial test cables will alter their attenuating effect, thereby affecting the accuracy of any RF measurements made with these cables in the circuit.

To reduce the danger of corrosion to untreated parts, always store test equipment in a dry place when it is not in use. Excessive dust and grime inside a test equipment also affects its accuracy. Be sure that all the assembly screws which hold the case of the test equipment in place are tightened securely. As an added precaution, all dust covers should be placed on test equipments when they are not in use.

Meters are the most delicate parts of test equipments. In order to insure that the meter will maintain its accuracy, these additional precautions should be followed:

1. Make certain that the amplitude of the input signal under test is within the range of the meter.
2. Keep meters as far away as possible from strong magnets.
3. When servicing an item of electronic equipment which contains a meter, disconnect the meter from the circuit before making resistance or continuity tests.

(The latter precaution will eliminate the possibility of burning out the meter.)

The instructions for properly stowing test equipment cables and other accessories, as set forth in the instruction manuals accompanying the equipment, should be carefully read and strictly followed. Improper stowage of accessories results in changes in cable characteristics, intermittent shorts in cables and leads, and, in general, causes unreliable test equipment indications.

MEASURING INSTRUMENTS

The term "measuring instruments," as used in this discussion, includes only that class of test equipments which measure the basic parameters of an electronic equipment. The basic parameters are (in this application) voltage, current, resistance, power, frequency, and field intensity.

The discussion of measuring instruments includes test equipment classes designated as multimeters, electronic voltmeters, frequency meters, line testers, signal generators, and multiple-function equipment.

REVIEW OF METER OPERATION

There must be some source of power available to operate a meter. Some meters are powered by batteries installed in the meter case, others are supplied through an electrical power cord which is plugged into a power receptable; a vacuum tube voltmeter (VTVM) is an example of the latter type. The power to operate some meters (such as the megger) is produced by manual operation of a handcrank. (The megger is discussed in chapter 3 of Basic Electronics Vol. 1, NavPers 10087-C.)

Most meters are designed to be used for measuring more than one electrical quantity, and are called multimeters. Before discussing any one particular type meter, a brief review of each of the basic meters is presented.

Ammeter

The amplitude of current flow through the basic meter mechanism limits it to measuring a fixed range of only a fraction of an ampere. To overcome this limitation, and to protect the mechanism, a current shunt is used. This device, which is actually a resistance of low value, permits the instrument to serve as a d-c ammeter in the measurement of relatively large direct currents.

The current distribution between meter movement and shunt is inversely proportional to their individual resistances. Thus, the shunt (which has less resistance) carries the majority of the current. Since the meter coil carries only a small portion of the circuit current, it is capable of indicating relatively large values of circuit current. The instrument may be adapted to a variety of current ranges by the use of shunts of different values which are switched in or out as required. Figure 5-1 shows a simplified schematic diagram of an ammeter-section taken from a typical volt-ohm-milliammeter.

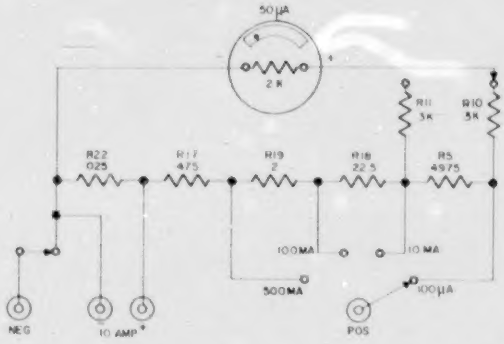

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Figure 5-1.—Simplified schematic diagram of an ammeter.

Ohmmeter

For any given ohmmeter, midscale deflection is obtained when the current drawn by the meter is one-half the value of the current at full-scale (zero ohms) deflection. This condition exists when the resistance being measured is equal to the total meter circuit resistance. Analysis of the circuit in figure 5-2 shows that full-scale deflection is obtained when the meter probes are shorted together, and that less than full-scale deflection is obtained when the resistance to be measured, R_x, is connected into the circuit. If the meter now reads one-half of its former current, it follows that the total circuit resistance has doubled, indicating that R_x is equal to the total meter circuit resistance.

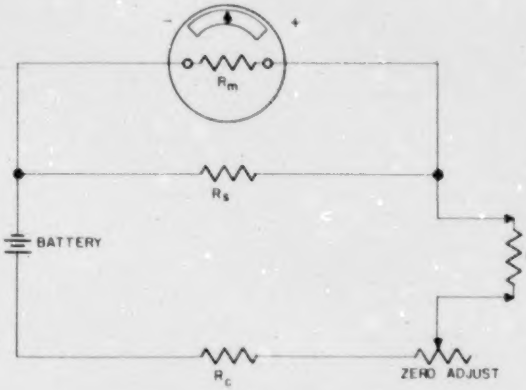

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Figure 5-2.—Series type ohmmeter basic circuit.

Since the ohms-calibrated scale is nonlinear, the midscale portion represents the most accurate portion of the scale. However, the usable range extends with reasonable accuracy on the high end to ten times the midscale reading, and on the low end to one-tenth of the midscale reading.

To extend the range of an ohmmeter, the proper values of shunt and series resistors and battery voltages are connected into the circuit so that with the test leads shorted the meter will read full scale. Figure 5-3 shows a simplified schematic diagram of an ohmmeter section taken from a typical volt-ohm-milliammeter.

Voltmeter

To make the basic meter mechanism suitable for measuring d-c voltages, the voltage multiplying resistor is added. The voltage multiplying resistor is placed in series with the coil (fig. 5-4) and limits the flow of current to a safe value.

Since the value of the resistor is constant for any given application, the flow of current through the coil is proportional to the voltage under measurement. By proper calibration of the dial, the instrument may be made to indicate voltage although it is actually activated by currents. In practice, the voltage ranges of the instrument are established by the use of different values of multiplying resistors.

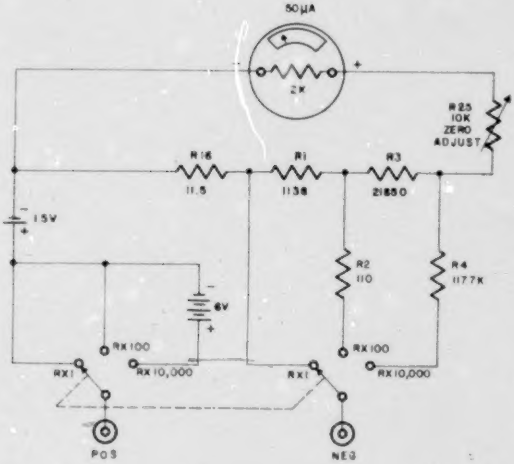

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Figure 5-3.–Simplified schematic diagram of an ohmmeter.

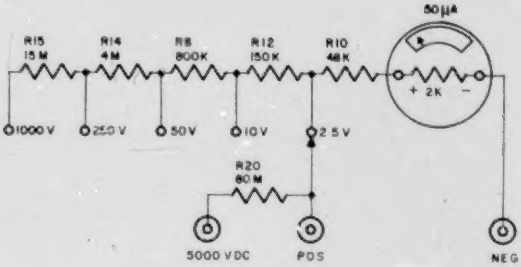

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Figure 5-4.–Simplified schematic diagram of a d-c voltmeter.

NONELECTRONIC METERS

Much of the technician's work requiring the use of a volt-ohm-milliammeter can be accomplished with a portable, battery-operated multimeter. Many shops employ the TS-352, Simpson 260, Simpson 160, or the PSM-4 for field use (troubleshooting in the aircraft, for instance). The technician will, however, often need a more sensitive meter–one that gives more accurate readings and has wider ranges.

Equipment schematics and wiring diagrams often specify that voltages indicated at test points were obtained by using a meter of a certain sensitivity, such as a 20,000-ohms-per-volt meter. **A meter of the same sensitivity** should be used when repairing that equipment in order to obtain accurate readings.

Multimeter AN/PSM-4C

The multimeter AN/PSM-4C (fig. 5-5) is designed to permit the technician to make measurements of voltage, resistance, and current with a completely self-contained portable instrument. It can measure either a-c or d-c voltage, d-c resistance, or direct current in a wide range of values. This capability covers the basic re-

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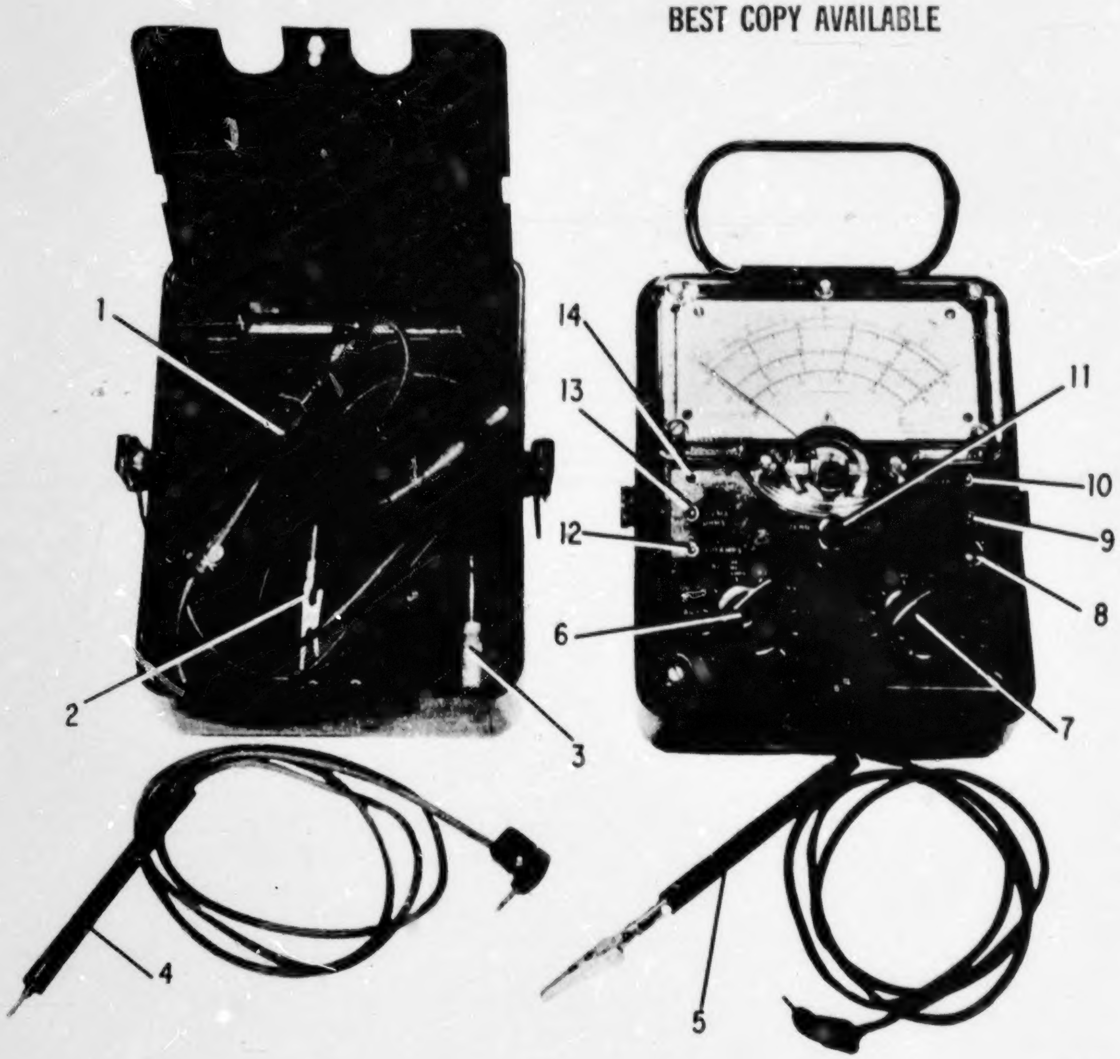


AQ.583

1. High voltage probe.
2. Alligator clips.
3. Telephone plug.
4. Standard test lead (red).
5. Standard test lead (black).
6. Function switch.
7. Current and voltage range selector.
8. +5,000 VDC multiplier.
9. +1,000 VDC (red lead).
10. 1,000 VAC (red lead).
11. Zero ohms.
12. +10 amps (red lead).
13. +Volts/MA/ohms (red lead).
14. Common (black lead).

Figure 5-5.—Multimeter AN/PSM-4C.

quirements for a portable tester of this type. All leads and accessories are stored in a compartment built into the cover, which remains with the instrument at all times. The cover forms a watertight seal when clamped over the face of the meter. While the instrument is in use, the cover clamps over the back of the meter keeping the accessory compartment convenient to the operator. Batteries used with the meter are: one BA-30 (1.5 volts) and one BA-261/U (22.5 volts).

In the accessory compartment there is a pair of standard test leads (one red and one black) which are used for most applications of the instrument. These leads have elbow probes on one end to connect the lead into the circuit jacks on the instrument. They have probe tips on the other end which have threaded shoulders to accept the alligator clips which are screwed on. These parts are used to make all measurements, except d-c voltage over 1,000 volts.

For measuring d-c voltages over 1,000 volts, a special high voltage probe is provided, and is used in conjunction with the standard black lead. One end of the lead has a threaded tip which screws on a post in the face of the meter (labeled 5,000 VDC MULTIPLIER). The other end of the lead has a high-voltage multiplier assembly made of red plastic with a clear plastic end and terminates in a crocodile clip at the end of a short piece of flexible wire. The clear plastic end allows the operator to observe the glow of a neon lamp when there is high voltage present. This is a warning to the operator that there is high voltage present at the clip and that he should not touch it. The neon lamp is in series with a 100-megohm resistor within the housing. When a high voltage is being measured, the current passes through the lamp making it glow, through the resistor, and through the armature of the meter.

There are three controls on the face of the meter. One is a 10-position rotary switch in the lower left-hand corner which is used as a function switch. Five of the positions on this switch are used to set up different resistance scales. Two of the positions are for selection of d-c voltage measurement (direct and reverse). The normal position of the switch is in the DIRECT position. If a negative voltage is to be measured, the switch is moved to the REVERSE position. (NOTE: Never switch leads to read a reverse or negative voltage.) One position of the switch is marked ACV; in this position the meter may be used to read a-c voltage. A rectifier in the instrument changes the a-c voltage to an equivalent d-c value which is applied to the meter. One position is marked OUTPUT; in this position the a-c portion of mixed a-c and d-c voltage may be read. The last position of the switch is used when measuring direct current and is marked DC with three ranges (μA, MA, AMPS) indicated to the right of the letters DC. In the lower right-hand corner is an eight-position switch used to select current and voltage ranges. Near the center of the meter is a control marked ZERO OHMS. This control has a continuously variable adjustment which is used to zero the meter, thus compensating for battery aging in the ohmmeter circuits. This control is adjusted until the meter indicates full-scale deflection (indicating zero ohms) when the function switch is set at one of the resistance range positions and the meter probes are shorted together. To prevent erroneous readings when switching to a different position, a check of the meter zero indication is always necessary.

The multimeter AN/PSM-4C is designed to make the following electrical measurements:

1. Measure direct current up to 10 amperes.
2. Measure resistances up to 300 megohms.
3. Measure d-c voltages up to 5,000 volts.
4. Measure a-c voltages up to 1,000 volts.
5. Measure output voltages up to 500 volts.

Input impedance for measuring d-c voltages is 20,000 ohms per volt and is accurate to within 3 percent of full scale (4 percent for the 5,000 VDC scale). When measuring a-c voltages, the input impedance is 1,000 ohms per volt and is accurate to within 5 percent of full scale.

Under normal conditions, no routine service inspection is necessary beyond visual examination at established inspection periods. If the instrument is to be stored for periods of 6 months or longer, the batteries must be removed to prevent corrosion. The periodic inspection should include removal of the battery case cover to facilitate inspection of battery connections. If the instrument is used under extreme temperature conditions, a visual inspection of all parts should be made at least once a month. No periodic maintenance is required except for inspection, test, and replacement of batteries.

ELECTRONIC METERS

Electronic meters are used primarily for the same purposes as the nonelectronic meters. Some characteristics of their operation, however, give them definite advantages. In the electronic multimeter, the current and resistance measuring circuits function in a manner identical to the corresponding nonelectronic measuring instruments. The measurement of voltage, however, involves the use of an amplifier which in turn requires that the meter be calibrated prior to use.

Proper calibration and use of the instruments vary slightly according to model. Details are included in the Operation Instruction Manual for each model.

Vacuum Tube Voltmeter TS-505

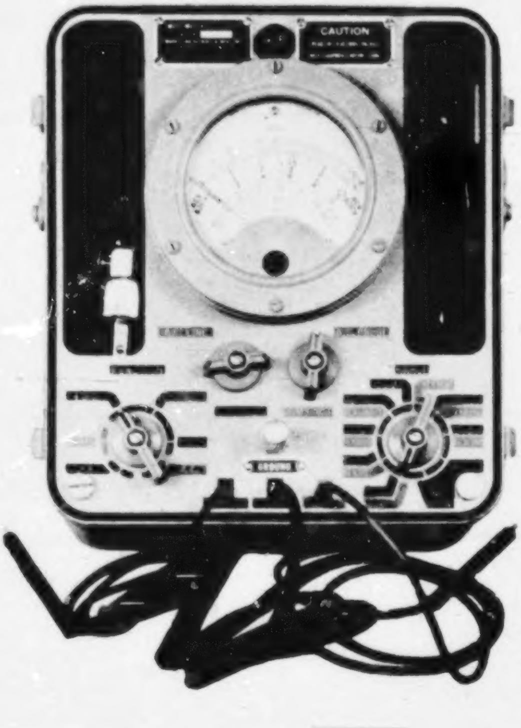
Figure 5-6 shows a front panel view of the TS-505. The VTVM measures d-c voltages from 0.05 volt to 1,000 volts (in 9 ranges), and a-c voltages from 0.05 volt to 250 volts rms (in 7 ranges), at frequencies from 30 Hz to 1 MHz. With the RF adapter that is used with the d-c voltage measurement circuit, RF voltages may be measured from 0.05 volt to 40 volts rms at frequencies from 500 kHz to 500 MHz. D-c resistances from 1 ohm to 1,000 megohms may be measured.

The accuracy of this meter is good, being 5 percent for d-c voltages and 6 percent for a-c and RF voltages. The meter movement requires 1 ma for full-scale deflection.

The input impedance to the meter is 6 megohms at audiofrequencies, 40 megohms on the 1,000-volt d-c range, and 20 megohms on all other ranges.

The power requirement is 98 to 132 volts, single phase, 50 to 1,000 Hz, at about 21 volt-amperes.

The removable cover of the TS-505 contains accessories such as alligator clips, an RF adapter, and miniature probe tips. The miniature tips slip over the regular tips when working in confined areas.



AT.94

Figure 5-6.—TS-505 multimeter, front panel.

OPERATING CONTROLS.—The controls that you will use when operating the meter (fig. 5-6) are as follows:

1. FUNCTION switch: Selects the type of multimeter operation desired and turns the multimeter on or off.

2. RANGE switch: Selects various voltage or resistance measurement ranges.

3. ZERO ADJ. control: Controls pointer of indicating meter. Used to set the meter pointer at zero on the +DC, −DC, AC, or OHM scale, or at midscale on the ±DC scale.

4. OHMS ADJ. control: Controls pointer of indicating meter. Used to set the meter pointer at ∞ on the OHMS scale when the FUNCTION switch is set on OHMS position.

5. Meter: Indicates the value of voltage or resistance measured.

6. AC LINE cord: Connects multimeter to a-c power source.

7. COMMON probe: Connects the ground, or common circuit of the multimeter, to the equipment under test.

8. DC probe: Connects equipment under test to the d-c measuring circuit of the multimeter.

9. OHMS probe: Connects equipment under test to the ohmmeter circuit of the multimeter.

10. AC probe: Connects equipment under test to the a-c measuring circuits of the multimeter.

11. Pilot light indicator: Lights when power is applied to the multimeter.

TECHNIQUES FOR USE.–The operation of this meter is virtually self-explanatory. By studying the controls and their respective markings, you should be able to determine the steps to follow when making a particular measurement. Do not attempt to use this instrument unless you have studied the technical manual which sets forth the operating procedures, or unless you have been instructed in its proper usage, under the direction of your work center supervisor.

Two peculiarities of this meter are:

1. In order for it to indicate accurate readings it must warm up. This usually takes about 10 minutes. During this period the meter pointer may drift rapidly; this is normal.

2. Voltage measurements cannot be read directly on the meter scale when the function switch is set at the ±DC position.

The purpose of the ±DC position (zero center scale) is to determine the polarity of an unknown d-c voltage or to indicate a zero d-c voltage input to the multimeter.

CAUTION: The maximum d-c voltage which may be applied to the multimeter when the function switch is set at the ±DC position is one-half of the voltage indicated by the panel marking opposite the range switch setting.

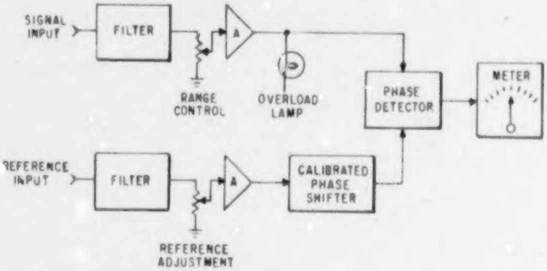
The major difference between any VTVM and a conventional multimeter is that the VTVM utilizes a vacuum tube in its input. For a detailed explanation of the circuitry of the TS-505 VTVM consult the manufacturer's manual or the Operation and Service Instruction Manual.

Phase Angle Voltmeters

The overall accuracy of many electronic equipments is determined by measuring phase angles in computing transformers, computing amplifiers, and resolver systems. In the past, one of the most common methods used for measuring phase shift or phase angles between signals was observing patterns on an oscilloscope. With this method, it was hard to determine small angles, and difficult to translate various points into angles and sines of angles. The most limiting factor in using oscilloscope patterns developed when one of the signals contained harmonic distortion or noise.

In any complex waveform containing a fundamental frequency and harmonics, measuring phase shifts presents problems. In most applications, interest lies in the phase relationship of the fundamental frequency, regardless of the phase relationship of any harmonics which may be present. One of the requirements of a phase measuring device is to measure the phase difference between two discrete frequencies, regardless of the phase and amplitude of other components of the waveform.

The basic block diagram of a phase angle voltmeter is shown in figure 5-7. There are two inputs–the signal and the reference. Both channels contain filters which pass only the fundamental frequency. All other frequencies are highly attenuated. Each channel has a variable



AT. 95

Figure 5-7.–Phase angle voltmeter, block diagram.

amplitude control and amplifiers to increase the variety of signals that can be checked.

A calibrated phase shifter is inserted into one channel; that channel signal can be phase shifted to correspond to the other channel. This is detected in the phase detector and observed on the meter.

The calibrated phase shifter is made up of a switch (whose position corresponds to the 0°, 90°, 180° and 270° phase shift) and a potentiometer (whose dial is calibrated from 0° to 90°). The total phase shift is made up of the sum of the two readings.

The phase detector is a balanced diode bridge type demodulator. Its output is proportional to the signal frequency amplitude times the cosine of the angle of phase difference between the signal input and the reference input.

If the reference input is phase shifted until it is in phase or 180° out of phase with the signal input, the output from the phase detector is proportional to the signal input amplitude (the cosine of the angle is unity). If the reference input is phase shifted until it is 90° or 270° from the signal input, the phase detector output is zero (the cosine of the angle is zero).

The point at which the two signals are in phase or 180° out of phase is the point of maximum deflection on the meter. The difference between the in phase and the 180° out of phase points is in the direction in which the needle swings—not the distance it swings. As the point of maximum deflection is approached, the rate of change of the meter reading decreases because the cosine has a small rate of change near 0°. This makes it difficult to read the exact point of maximum deflection.

Because the cosine has a maximum rate of change as it approaches 90° (and thus gives a better indication on the meter), most commercial voltmeters are set to determine the point at which the signals are 90° out of phase—"quadrature." When the voltmeter is set for this point, there must be some way of converting the phase shifter reading so that it shows the correct amount of phase shift rather than 90° more or less than the actual amount. Some confusion exists in this area because different manufacturers have different methods of determining the signal quadrant. Manufacturers also differ on whether the final reading is a leading or a lagging phase shift. This means the technician must be familiar with as many types of phase angle voltmeters as the Navy has in the field. He cannot assume that the method he uses to determine phase angle on one type of meter can be used on another: nor can be assume that, because one meter gives him a leading angle between signal and reference waveforms, another manufacturer's meter also gives leading phase shift.

Differential Voltmeter

The differential voltmeter is a reliable precision item of test equipment. Its general function is to compare an unknown voltage with an internal reference voltage, and to indicate the difference in their values. The differential voltmeter in most common use in Navy applications is the 803D/AD (fig. 5-8), manufactured by the John Fluke Co. The remaining portion of this discussion is based on that instrument.

The 803D/AD is usable as an electronic voltmeter, as a precision potentiometer, and as a megohmmeter. It can also be used to measure the excursions of a voltage about a reference value. Ease of operation, inherent protection from any accidental overload, and high reliability of readings are additional advantages of the instrument. It is accurate enough for precision work in calibration laboratories, yet rugged enough for general shop use.

The heart of the unit is a precision 500-volt d-c reference power supply. This 500 volts can be precisely divided into increments as small as 10 microvolts by means of 5 voltage dials. Unknown a-c or d-c voltages are matched against the precise internal voltage until no deflection occurs on the panel meter. The unknown voltage is then simply read from the voltage dials. In the highest null sensitivity range, a potential difference between unknown and reference voltage as small as 0.01 volts causes full-scale meter deflection.

At null, the differential voltmeter presents an "infinite" input impedance to the voltage under measurement, almost completely eliminating circuit loading.

A functional schematic diagram of the differential voltmeter is shown in figure 5-9. The principal circuit divisions are as follows:

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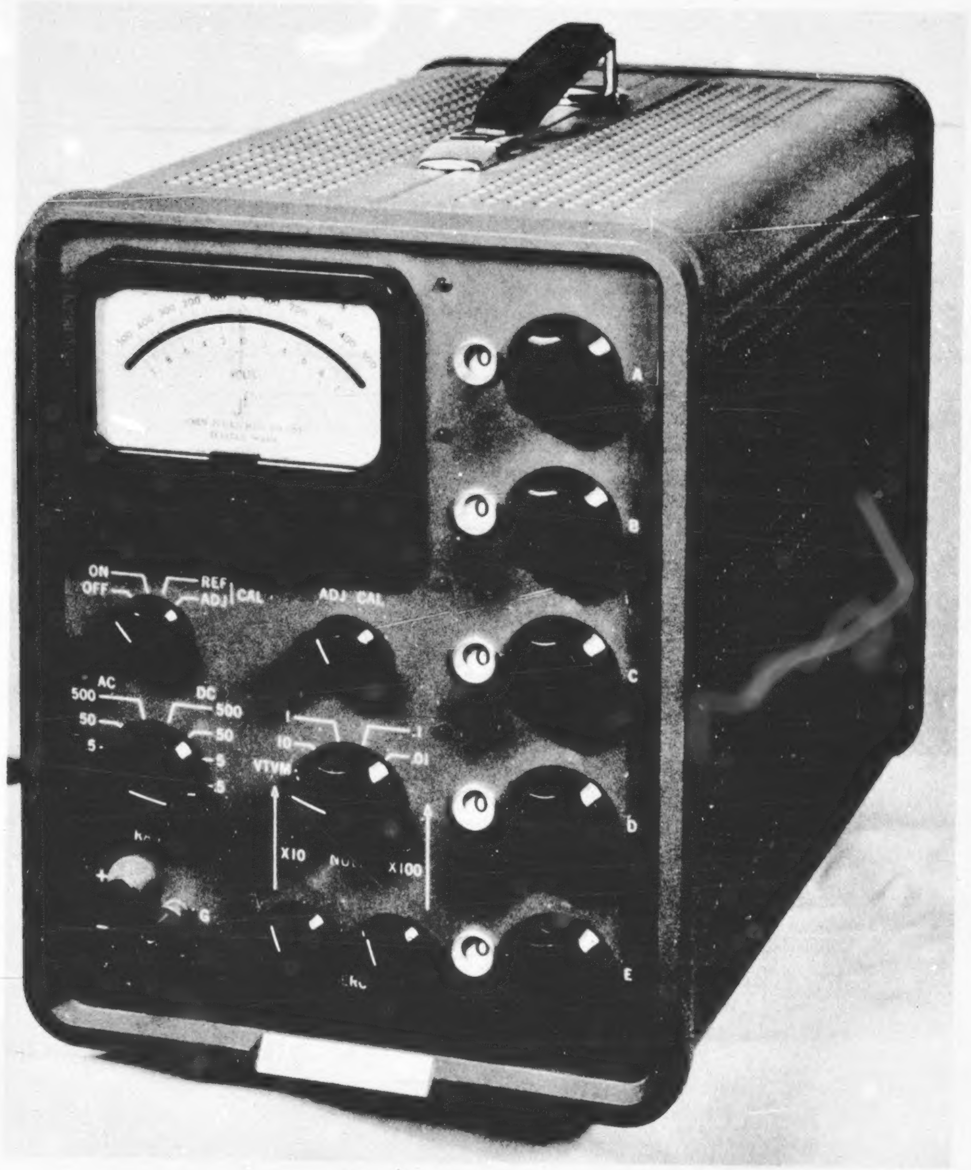
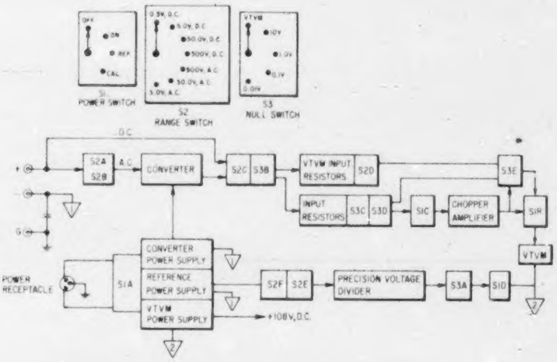

ON
OFF
REF
ADJ
CAL
ADJ CAL
AC
DC
500
50
5
500
50
5
.5
1
10
VTVM
.1
.01
X10
X100
A
B
C
D
E
G

AT. 96

Figure 5-8.—Differential voltmeter, Model 803D/AD.


OFF
ON
REF
CAL
S1
POWER SWITCH
0.5V, D.C.
5.0V, D.C.
50.0V, D.C.
500V, D.C.
500V, A.C.
50.0V, A.C.
5.0V, A.C.
S2
RANGE SWITCH
VTVM
10V
1.0V
0.1V
0.01V
S3
NULL SWITCH
D.C.
A.C.
S2A
S2B
CONVERTER
S2C
S3B
VTVM INPUT RESISTORS
S2D
S3E
INPUT RESISTORS
S3C
S3D
S1C
CHOPPER AMPLIFIER
S1R
VTVM
G
POWER RECEPTACLE
S1A
CONVERTER POWER SUPPLY
REFERENCE POWER SUPPLY
VTVM POWER SUPPLY
+108V, D.C.
S2F
S2E
PRECISION VOLTAGE DIVIDER
S3A
S1D
1
2

AT. 97

Figure 5-9.—Differential voltmeter, functional schematic diagram.

1. A 500-volt d-c reference power supply.
2. Precision voltage divider network.
3. VTVM.
4. Chopper-amplifier.
5. Converter and converter power supply.

The system circuitry is designed with two separate common returns. One of these, the return for the converter power supply and reference power supply, provides a safety factor for personnel and a capability for measuring a potential difference between two voltages. The other, which is the common return of the VTVM power supply, is connected to the known reference voltage output from the precision voltage divider network. This arrangement provides a constant d-c voltage of +108 volts across the differential amplifier regardless of the d-c potential applied to the grid.

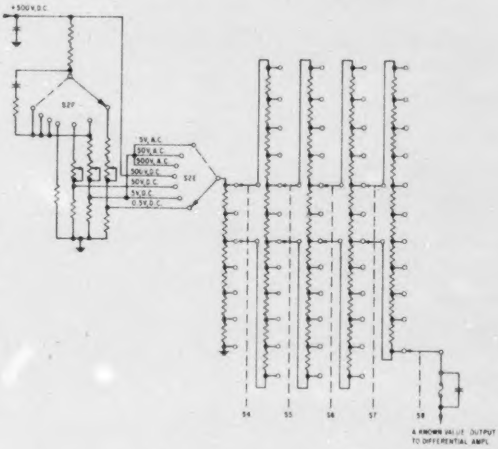
D-C REFERENCE POWER SUPPLY.—A full wave rectifier with its associated filter network supplies a d-c voltage of approximately 1,000 volts to a conventional electron controlled voltage regulator. The regulated output is maintained at 500 volts ±0.01 percent.

In the 500 V DC position, the RANGE switch (S2E) passes this 500 volts directly to the precision voltage divider. In the 50 V DC, 5 V DC, and 0.5 V DC positions, range resistors S2F divide the reference voltage to 50, 5, and 0.5 volts d.c., respectively. In all a-c positions of the RANGE switch, only 5 volts of the reference supply is used, due to the fact that the maximum output of the a-c to d-c converter is 5 volts.

PRECISION VOLTAGE DIVIDER.—Each of the four precision voltages available from the reference supply must be made adjustable through a precision divider network so that unknown voltages may be nulled or matched exactly. The five decade resistor strings (fig. 5-10) accomplish this function.

Note that each string, with the exception of the first, parallels two resistors of the string that precedes it. Between the two wipers of S4, there is a total resistance of 40K and a total voltage of 100 volts d.c. with the RANGE switch in the 500 V DC position. Across the wipers of S5, S6, and S7, there are 10, 1, and 0.1 volts d.c., respectively. Switch S8 selects increments of 0.01-volt d.c. from the last decade. These voltages are reduced by a factor of 10 for each successively lower voltage range.

All resistors of each decade are matched and all decades are matched for each instrument,


+500V, D.C.
S2F
5V, A.C.
50V, A.C.
500V, A.C.
500V, D.C.
50V, D.C.
5V, D.C.
0.5V, D.C.
S2E
S4
S5
S6
S7
S8
A KNOWN VALUE OUTPUT TO DIFFERENTIAL AMPL

AT. 98

Figure 5-10.—Precision voltage divider.

providing an overall divider accuracy of 0.005 percent.

With the NULL switch in any null range, the output of the precision voltage divider appears at the grid of one-half of the VTVM differential amplifier. A one two-hundredths ampere (5 milliampere) fuse protects this output.

VACUUM TUBE VOLTMETER.–When operating in the differential mode, output voltage from the precision voltage divider appears on the grid of V4B, one-half of the differential amplifier. (See fig. 5-11.) The unknown voltage appears on the grid of V4A, the other half of the differential amplifier. Any difference between these potentials is indicated by the meter coupled between the cathodes of V4A and V4B. When the output voltage exactly matches the unknown, the meter reads zero and no current is drawn from the source being measured, because the same potential exists on both sides of the input resistances.

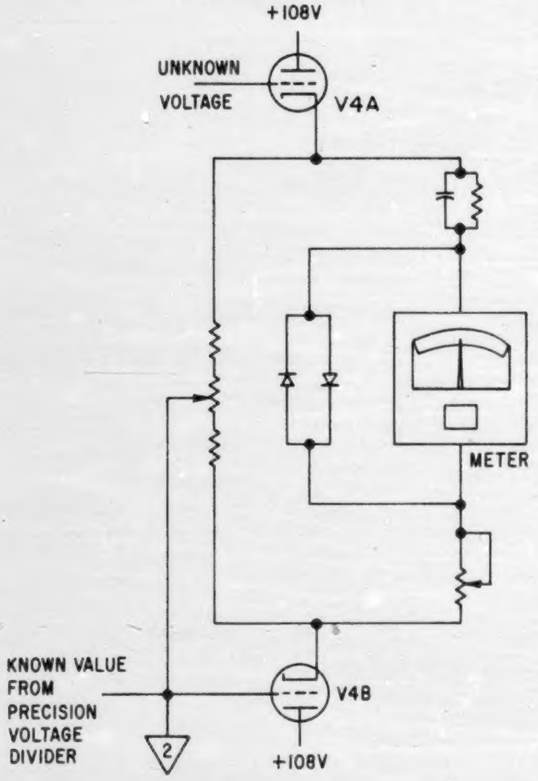


Figure 5-11.–Differential amplifier.

When used as a conventional VTVM, the grid of V4B is connected to the 0-volt bus, or negative binding post. With the range switch in the 0.5 V DC position, the unknown voltage appears directly on the grid of V4A and the meter indicates the approximate value of the unknown. Input divider resistors maintain the 0 to 0.5 grid voltage range for all instrument voltage ranges. The input resistance of the instrument in the VTVM position is 10 megohms.

CONVERTER.–All a-c measurements are made by first converting the a-c input to a d-c voltage. The converter provides a maximum d-c output of 5 volts for a maximum a-c input of 5 volts rms. In the 5 V AC position, range switch sections of S2A and S2B couple the converter amplifier input directly to the binding post. In the 50 V AC and 500 V AC positions, input attenuators reduce the unknown a.c. to provide a maximum of 5 volts a-c input to the first converter amplifier.

The overall frequency response of the converter is essentially flat from 30 Hz to 10 kHz.

Model 5015 SPA Digital Voltmeter

The Model 5015 SPA Digital Voltmeter provides users a highly accurate, easily maintained instrument which also possesses a high order of reliability. The meter uses a relay-operated digital feedback voltage divider, energized by a 10-volt Zener reference voltage, to create a precision feedback voltage equal to the unknown input.

Continuous comparison is made between the feedback voltage and the unknown input; any error voltage is amplified and used to reposition the feedback voltage divider.

An automatically operated attenuator provides operation on the 100-volt and 1,000-volt ranges by dividing the inputs by 10 and 100, respectively. Matched and aged Zener diodes eliminate the need for a temperature-controlled oven.

The Model 5015 SPA digital voltmeter (fig. 5-12) has seven front panel controls. Their functions are described in the following paragraphs:

1. The SENSITIVITY control is a potentiometer that is provided to decrease sensitivity for noisy signals.

2. The FILTER switch is provided to engage or remove the filter application.

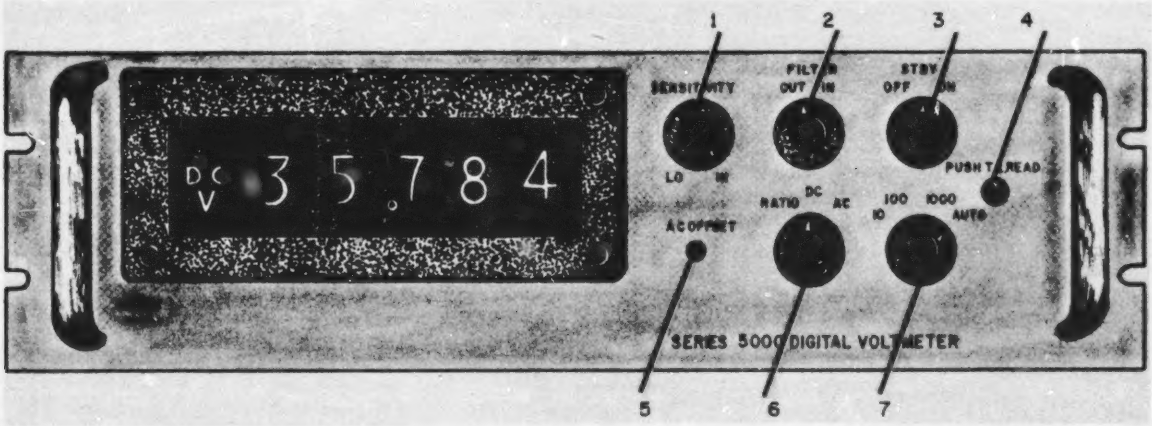
3. The power switch has three positions: (1) OFF—the digital voltmeter is deenergized and both power leads are isolated from the power source; however, connection is maintained between the outer case and the a-c power line ground. (2) STBY—this position is provided to allow a warm up selection without any activation of internal components even with an input signal applied. (See paragraph on PUSH TO READ for exception.) (3) ON—in this position the digital voltmeter is ready to provide measurement readings of input signals.

4. With an input signal applied and the power switch in the STBY position, depressing the PUSH TO READ switch permits the operator to take a single reading.

5. The AC OFFSET control is a screwdriver adjust potentiometer provided to "zero" the readout in the AC mode prior to taking a-c readings.

6. The function switch is provided to permit the selection of either the RATIO, DC volts, or AC volts modes of operation.

7. The range switch has four positions: (1) The 10, 100, and 1,000 positions are used to fix the maximum voltage which will be read. (2) The AUTO position causes the digital voltmeter to select automatically the appropriate range for the input applied.



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1. SENSITIVITY control.
2. FILTER switch.
3. Power switch.
4. PUSH to READ switch.
5. AC OFFSET control.
6. Function switch.
7. Range switch.

Figure 5-12.—Model 5015 SPA digital voltmeter front panel controls.

FREQUENCY MEASUREMENTS

Frequency measurements are often an essential part of preventive and corrective maintenance for electronic equipment. Rotation frequencies of some mechanical devices must be determined. The output frequency of electric power generators is checked when the engine is started and during preventive maintenance routines. Equipment which operates in the audiofrequency range must be adjusted to operate at the correct frequencies. Radio transmitters must be accurately tuned to the assigned frequencies to provide reliable communications and avoid interfering with radio circuits operating on other frequencies. Radar sets must be properly tuned to obtain satisfactory performance.

The rotation frequency of rotating machinery such as radar antennas, servomotors, and other types of electric motors can be measured by the use of a stroboscope. Stroboscopic methods compare the rate of one mechanical rotation or vibration with another or with the frequency of a fluctuating source of illumination. Tachometers can be used to measure the rotation frequency of armatures in electric motors, dynamotors, and engine-driven generators.

The electrical output frequency of a-c power generators can be measured directly by vibrating reed, tuned circuit, or crossed-coil iron-vane type meters. The vibrating reed device is the simplest type of frequency meter, and has the advantage of being rugged enough to be mounted on generator control panels. It is also used to check the line voltage in the shop to insure that the proper frequency is supplied to the equipment and/or test sets.

FREQUENCY METERS

Frequency meter is a term generally applied to denote an item of test equipment which is used to indicate the frequency of an external signal. Although some models of frequency meters generate signals having a basic frequency, they should not be confused with that class of test equipment known as signal generators. (Signal generators are discussed later in this chapter.) The signal generator develops a frequency used to operate an external circuit; the frequency meter measures the frequency of a signal developed in an external circuit.

As mentioned previously, some frequency meters generate a signal frequency; others do not. The group in which no frequency is generated internally is properly called a "wavemeter." Wavemeters are of two basic types—reaction and absorption. Those frequency meters which do generate an internal frequency may use either electronic or mechanical oscillation as the frequency generator.

Measurement Methods

Frequency measurements in the audio frequency range can be made by the comparison method or by a direct-reading frequency meter. Frequency comparisons can be made by the use of a calibrated audiofrequency signal generator in conjunction with either an oscilloscope or a modulator and a zero-beat indicator device. Direct-reading frequency measurements can be made by instruments using series frequency-selective electrical networks, bridge test sets having null indicators, or counting type frequency meters.

Frequency measurements for radio equipment are made during tuning, preventive maintenance, and corrective maintenance procedures. The type of test equipment selected depends on the frequency to be measured and the required accuracy. Signal frequencies of radio transmitters which operate in the low frequency to the VHF range are normally measured by absorption type wavemeters, reaction type wavemeters, or calibrated radio receivers. Where accuracy is not of prime importance, rapid frequency checks may be made by the absorption type wavemeter. Since the wavemeter is relatively insensitive, it is very useful in determining the fundamental frequency in a circuit generating multiple harmonics. Calibration of test equipment that measure signals in this frequency range can be checked by comparison with standard frequency signals broadcast by the National Bureau of Standards.

The signal frequencies of radio and radar equipment which operate in the UHF and SHF range can be measured by resonant cavity type wavemeters, resonant coaxial line type wavemeters, or Lecher-wire devices. When properly calibrated, resonant cavity and resonant coaxial line wavemeters are more accurate and have better stability than wavemeters used for measurements in the low frequency to VHF range. These frequency-measuring instruments are often furnished as part of communication and electronic equipment, but are also available as general purpose test sets.

WAVEMETERS

Wavemeters are calibrated resonant circuits used to measure frequency. Any type of resonant circuit may be used in wavemeter applications. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low frequency wavemeters. Butterfly circuits, adjustable transmission line sections, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters—the absorption, the reaction, and the transmission types.

Absorption wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator, and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency.

The setting of the wavemeter dial is made by observing the grid current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radiofrequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies. Units of this type are included in echo boxes. The additional provisions for echo boxes permit additional testing functions.

Many actual wavemeters are used in performing various functions. Cavity type wavemeters are the type most commonly used, and only this type is discussed in detail.

Cavity Wavemeters

Figure 5-13 shows a typical cavity wavemeter. The wavemeter illustrated is of the type commonly used for the measurement of microwave frequencies. The device employs a resonant cavity which effectively acts as a high-Q, LC tank circuit. The resonant frequency of the

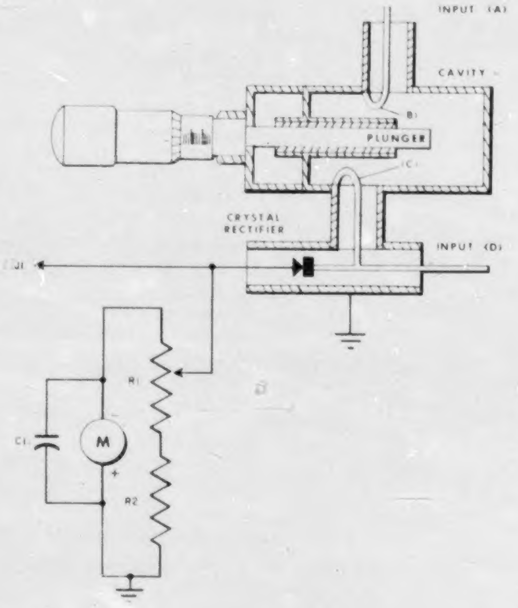

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Figure 5-13.—Typical cavity wavemeter.

cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through one of two inputs, A or D. A crystal rectifier then detects (rectifies) the signal, and the rectified current is indicated on the current meter, M.

This specific instrument can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the circuit by means of input A. When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop B into the cavity and out through loop C to the crystal rectifier. It is rectified and current flow resulting from this rectification is indicated on the meter. At frequencies off resonance, little or no current flows in the detector and the meter reading is small. The micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type of device. Connection is made to the instrument at the input D. The RF loop C then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, maximum energy is absorbed by the cavity and the meter dips, indicating a reduction of current. When the cavity is not tuned to the frequency of the klystron, high current is indicated on the current meter. Therefore, the cavity is tuned for a minimum reading, or dip, in the meter; and the resonant frequency is determined from the micrometer setting and the calibration chart.

Potentiometer R1 is used to adjust the sensitivity of the meter from the front panel of the instrument. J1 is a video jack and is provided for observing video waveforms with a test oscilloscope.

A directional antenna is used in conjunction with the instrument for making relative field strength measurements of radiated signals, for use in measuring the frequency of radar transmitters, and for constructing radiation patterns of transmitting antennas.

In radiation pattern measurements, the directional antenna is connected to the wavemeter input, and the instrument is tuned to the frequency of the system under test. The cavity is then locked on this frequency by an AFC system. The output signal being measured must be continuous and constant for reliable results. This is necessary in order for any variation in the meter reading to be caused directly by a change in the actual field strength of the signal when the position of the wavemeter is changed with respect to the transmitting antenna. After establishing a reference level on the meter, the position of the wavemeter is then changed by moving it around the radiating antenna, maintaining a fixed distance from it. The wavemeter readings at various positions around the transmitting equipment are recorded on polar graph paper, and the field pattern is thereby determined.

COUNTER TYPE FREQUENCY METER

The counter type frequency meter is a high-speed electronic counter with an accurate, crystal-controlled time base. This type of combination provides a frequency meter which automatically counts and displays the number of events occuring in a precise time interval. The frequency meter itself does not generate any signal, but merely counts the recurring pulses fed to it.

Frequency Meter AN/USM-26

Frequency Meter AN/USM-26 is a precision instrument that automatically measures frequencies to 100 MHz and automatically displays its measurements in digital form on an eight-place panel indicating system. In addition to making direct measurements of frequency, the AN/USM-26 also measures period (time of one cycle of periodic wave), time intervals, and frequency ratios, and may be used to count random events such as those encountered in nuclear work. The equipment further includes a self-check feature that enables the operator to verify the proper operation of the equipment for most types of measurements.

By use of the Frequency Converter AN/USA-5 plug-in unit, the useful operating range of the USM-26 is extended to 220 MHz. Similarly, using the Transfer Oscillator CM-102/USM-73 in conjunction with the USA-5 further extends the frequency range to the vicinity of 5 GHz (gigahertz) before the harmonics become too weak for use. Use of a tunable detector allows the operator to resonate the signal to be measured, thus increasing the sensitivity of the equipment for detection of harmonics. This extends the upper limit of operation to about 12 GHz. A second tunable detector can be used to further increase the sensitivity by resonating the desired harmonic produced by the transfer oscillator.

Because of the accuracy with which it measures frequencies, the USM-26 equipment can be considered to be a new type of secondary frequency standard that replaces more elaborate installations of conventional precision frequency-measuring equipment. For example, the meter has been found particularly useful for frequency measurements in quartz crystal grinding work as well as for general laboratory quality frequency measurements. Other typical frequency-measuring applications for the equipment include calibration of transmitters, oscillators, signal generators, etc.

In combination with tachometer generators or other suitable transducers, the equipment can be used to make precision tachometry measurements. In tachometry work it is particularly useful for measuring the rotation frequency of high speed devices. When used in conjunction with a sensitive radioactivity detector and a suitable transducer, the USM-26 can provide an extremely accurate indication of the radioactivity radiation level.

Time measurements that the equipment will make include pulse length, pulse interval, time delay, etc.

Since the indicating system in the equipment presents the measured frequency in as many as eight significant figures, the equipment is especially useful for measuring very small frequency changes such as are encountered when making measurements of frequency stability of oscillators and similar frequency generators.

Electronic Counter 524D

A counter type frequency meter (fig. 5-14), Electronic Counter 524D (Hewlett-Packard), can measure frequencies from 10 Hz to 10.1 MHz and display the readings in digital form on an eight-place indicating system. In addition to making direct frequency measurements, they can measure periods (0 Hz to 100 kHz), frequency ratios, and total events. A self-check feature enables an operator to verify instrument operation for most types of measurements. The internal oscillator is stable within 5 parts of 10^8 per week. Thus these counters make good secondary frequency standards.

To increase the range of measurement, seven accessory plug-in units (not shown) are available. Frequency Converter Units, Models 525A, B, and C, increase the frequency range from 10.1

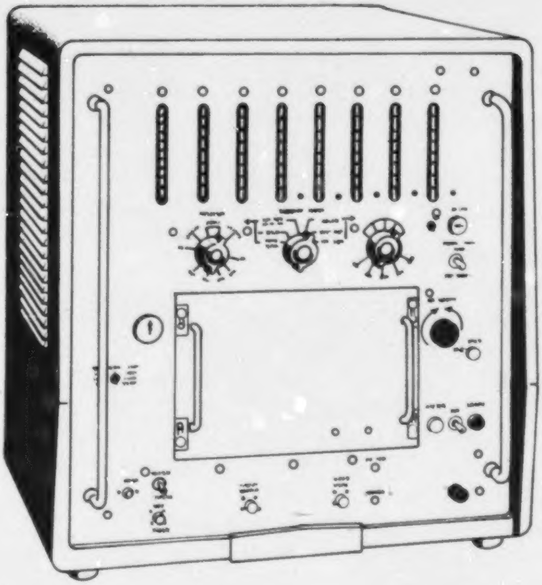

Figure 5-14.—Electronic counter, 524D.

MHz to 100 MHz, 100 MHz to 220 MHz, and 100 MHz to 510 MHz, respectively. Video Amplifier unit 526A increases the basic set sensitivity to 10 mv in the range of from 10 Hz to 10.1 MHz; Time Interval unit 526B permits measuring time intervals from 1μsec to 10^7 seconds; Period Multiplier unit 526C extends the period measurement range up to 10,000 periods of unknown frequency; and Phase unit 526D permits measuring phase angle with an accuracy approaching ±0.1°. In addition to the plug-ins, the Model 540B Transfer Oscillator extends, as a companion instrument, the frequency range up to 12.4 megahertz (10^9 accuracy).

To measure frequency the basic circuit arrangement of the electronic counter is shown in figure 5-15. For frequency measurement the signal is fed through a Signal Gate to a series of digital type counters. A precision time interval obtained from the Time Base Section opens and closes the Signal Gate for an extremely accurate period of time, for example, 1 second. The counters count the number of cycles entering through the gate during the 1-second interval and then display the total. The answer is read directly as the number of kilohertz occurring during the 1-second interval. The period of time the Signal Gate remains open is set by the FREQUENCY UNIT switch (not shown). For each position of the FREQUENCY UNIT switch the illuminated decimal point is automatically positioned so that the answer is always read directly in kilohertz. The answer is automatically displayed for a period of time determined by gate time or the setting of the DISPLAY TIME control on the front panel, whichever is greater.

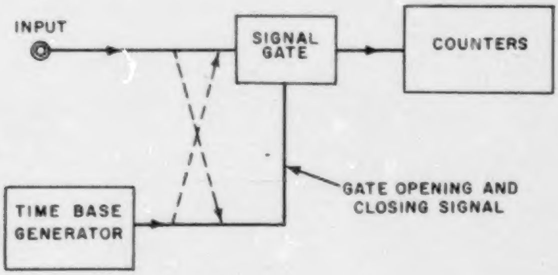

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Figure 5-15.—Basic block diagram of the 524D.

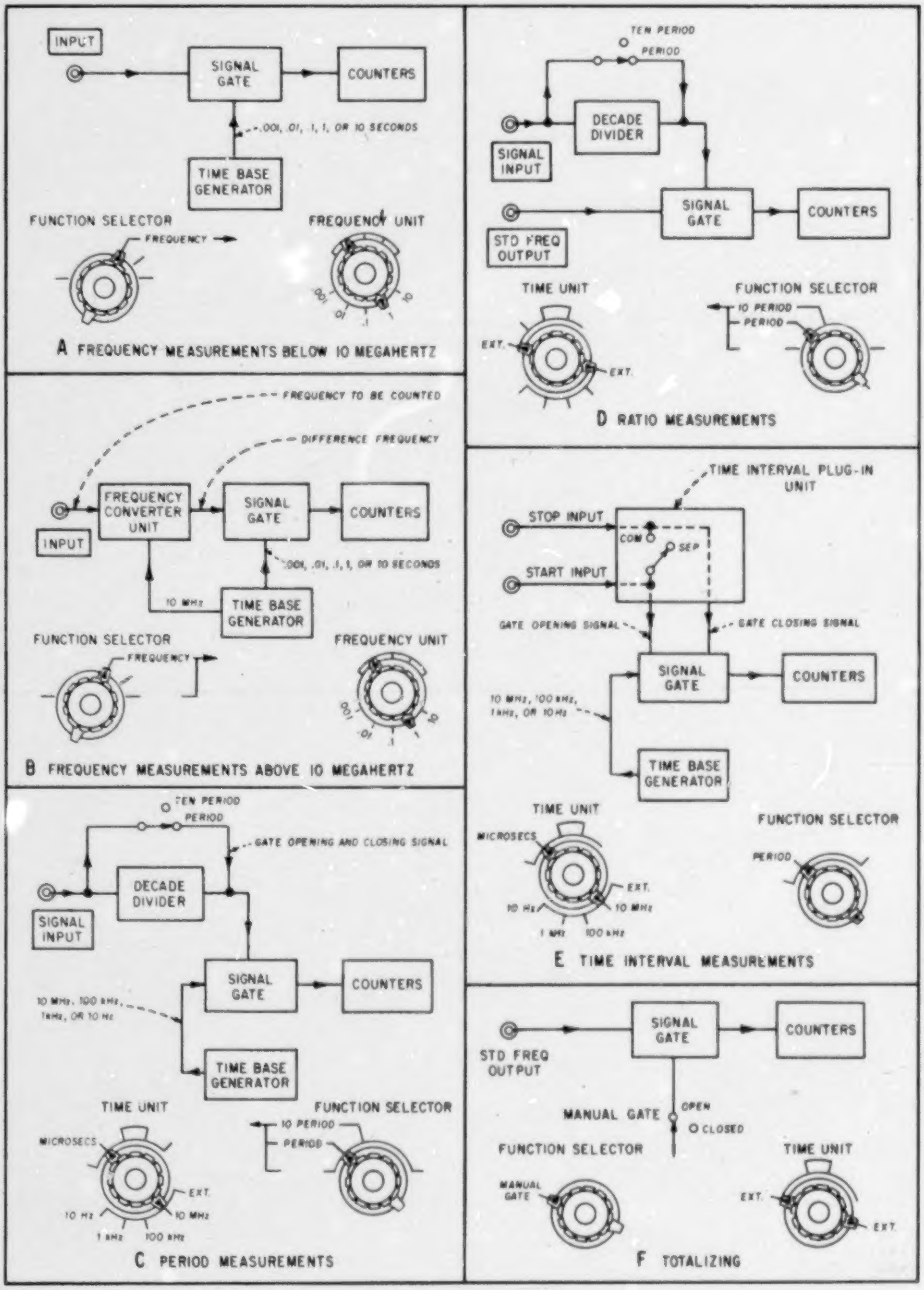
To measure a period or time interval the application of the two signals reverses as shown by the dotted lines in figure 5-15. The period or time interval to be measured is connected to open and close the Signal Gate while one of the standard frequencies from the Time Base Section is passed through the Signal Gate to the counters. When measuring period, one cycle of the incoming signal opens the gate, the next cycle closes it, The number of cycles of the standard frequency from the Time Base that occurred during the period are then indicated on the counters. The standard frequencies obtained from the Time Base have been selected so that the answer to the measured period will always be displayed in direct-reading units of time: seconds, milliseconds, or microseconds.

Provision is also made in the circuit to permit measurement of the average of 10 periods of the unknown frequency. Higher accuracy can thus be obtained than with single period measurements.

The accuracy of frequency measurements is determined by an internal oscillator and by a possible error of ±1 count that is inherent in the gate and counter type of instrument. At low frequencies, greater accuracy can be obtained by measuring the period of the signal than by measuring the frequency directly.

The block diagram (fig. 5-16 (A)) shows the circuit arrangement of the basic counter when measuring frequencies in the range of 10 Hz to 10.1 MHz. To measure frequencies up to 510 MHz, one of three frequency converter units is required (fig. 5-16 (B)). As stated above, the 525C Frequency Converter unit is used between 100 and 510 MHz. In these frequency converters the input signal is mixed with a harmonic of 10 MHz so that the difference between the signal and the harmonic is not more than 10.1 MHz. The difference frequency is counted and displayed. By adding the count displayed by the counter to the known 10 MHz harmonic the input signal frequency is determined.

All three frequency converters have tuning systems to indicate the correct mixing fre-



A FREQUENCY MEASUREMENTS BELOW 10 MEGAHERTZ

B FREQUENCY MEASUREMENTS ABOVE 10 MEGAHERTZ

C PERIOD MEASUREMENTS

D RATIO MEASUREMENTS

E TIME INTERVAL MEASUREMENTS

F TOTALIZING

INPUT
SIGNAL GATE
COUNTERS
.001, .01, .1, 1, OR 10 SECONDS
TIME BASE GENERATOR
FUNCTION SELECTOR
FREQUENCY
FREQUENCY UNIT
.001
.01
.1
1
10
FREQUENCY TO BE COUNTED
DIFFERENCE FREQUENCY
FREQUENCY CONVERTER UNIT
10 MHz
TEN PERIOD
PERIOD
GATE OPENING AND CLOSING SIGNAL
DECADE DIVIDER
SIGNAL INPUT
10 MHz, 100 kHz, 1kHz, OR 10 Hz
TIME UNIT
MICROSECS
EXT.
10 Hz
1 kHz
100 kHz
10 PERIOD
STD FREQ OUTPUT
TIME INTERVAL PLUG-IN UNIT
STOP INPUT
START INPUT
COM
SEP
GATE OPENING SIGNAL
GATE CLOSING SIGNAL
MANUAL GATE
OPEN
CLOSED

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Figure 5-16.—Test measurement, block diagram.

quency. However, if the mixing frequency is within 1 MHz of the unknown frequency, there is a possibility of two answers, for you may not know whether to add or subtract the displayed reading from the mixing frequency. In such cases, make additional measurements using the two adjacent mixing frequencies to determine the unknown frequency. When making the final measurement choose a mixing frequency which is at least 100 kHz away from the unknown.

When measuring frequency, the counter will count sine waves, rectangular waves, and positive pulses. To measure the frequency of negative pulses, adjustment of a FREQUENCY sensitivity control is necessary. This control is a screwdriver adjustment located on the front panel.

When the counter is set for PERIOD measurements, the time base and the signal input circuits are interchanged from their frequency measurement positions (fig. 5-16 (C)). With the circuits so connected, the counters count the output of the time base for the period of the unknown input signal. Thus the standard frequencies generated in the time base are used as units of time to measure the unknown period in terms of microseconds, milliseconds, or seconds.

The accuracy of period measurements is largely determined by the accuracy with which triggering occurs at the same point on consecutive cycles of signal voltages having a slow rate-of-rise. Note that when the signal-to-noise ratio improves, the triggering accuracy also improves. Averaged over 10 periods, the single-period error is reduced by a factor of 10. If the 526C Period Multiplier unit is used, the error is reduced an additional factor of 10 for each factor the measurement is extended. The accuracy of triggering is considerably improved when the waveforms being measured have a fast rise time. For example, a significant reduction in error can be obtained if square waves are applied instead of sine waves to the input.

In order to follow the slowest-changing waveforms, the period measurement input circuits are direct-coupled and are adjusted to trigger at the zero-volt crossing of a negativegoing voltage. Thus any d-c component in the input signal will shift the triggering level so that the maximum slope no longer occurs at the zero-volt level, resulting in a loss of accuracy. If the d-c component is large enough, there may be no triggering at all. An external generator can be used in place of the time base generator for period measurements.

The counter can be used to measure the RATIO of two frequencies. The higher frequency is passed through the signal gate to the counters and is counted for a period of time determined by either one period or 10 periods of the lower frequency, which controls the opening and closing of the gate (fig. 5-16 (D)).

Ratio measurement accuracy is determined by the same factors as period measurement accuracy: consistency of triggering by the lower input frequency and the inherent error of ±1 count of the higher frequency. The 526C Period Multiplier unit is used to reduce the error by extending the number of periods of the lower frequency over which the measurement is made. For each factor of 10 the measurement is extended, the error is decreased by a factor of 10.

Although the time base generator is not used during ratio measurements, ratio measurements cannot be made if the time base generator is not operating. The counter has a holdoff circuit which disables the signal gate if the time base generator fails.

To make TIME INTERVAL measurements (fig. 5-16 (E)), the 526B time interval unit must be installed. Time interval measurements are similar to period measurements except that the points on the signal waveforms at which the measurement starts and stops are adjustable. The adjustable threshold feature allows you to make measurements from one part of the same waveform or to use separate waveforms as start and stop signals.

As in the case of period measurements, the input signals control the opening and closing of the gate while the standard frequencies are passed to the counters (fig. 5-16 (E)). Thus the accurate frequencies generated in the time base are used as units of time to measure the unknown interval in terms of microseconds, milliseconds, or seconds.

The 526B time interval unit may also be used as a high-speed totalizer capable of counting at a maximum rate of 10.1 million events per second. The basic circuit arrangement is indicated in figure 5-16 (F).

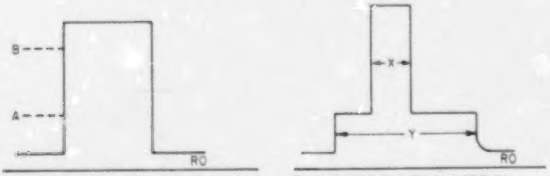
The threshold-selecting controls adjust the start and stop channels so that they will be actuated only by signals of predetermined polarity, amplitude, and slope. Time interval measurements begin when the start signal crosses the selected start threshold value in the selected direction and end when the stop signal crosses the selected stop threshold value in the selected direction. The threshold controls are only approximately calibrated and,in some applications, special precautions will have to be taken in order to obtain the desired interval.

If an uncomplicated waveform is used as the start and/or stop signal, the setting of the threshold controls is not critical. For example, if a sharp pulse like that shown in figure 5-17 (A) is used, there will be little difference whether the measurement begins at point A or B. However, if a more complex waveform like that shown in figure 5-17 (B) is used to measure the interval X, set the threshold controls near zero as a preliminary adjustment. As the start and then the stop threshold controls are adjusted notice the definite changes in the measured time interval. Thus the start and stop thresholds are above the step and the indicated time interval is actually X.

It is highly desirable to examine both start and stop signals on a d-c coupled oscilloscope before attempting a measurement. In this way it can be determined that no spurious signals exist, and the threshold controls can be carefully set.

With a 526D phase unit plugged into the counter, the phase angle between two signals of identical frequency, in the range from 1 Hz to 20 kHz, may be measured. This unit is useful for investigating, at various points in a circuit, the phase a signal has with respect to the phase it had at the input. Connect the reference signal to the REFERENCE INPUT, and the signal whose phase is under investigation to the UNKNOWN INPUT. If the frequency of the signal is 400 ± 4 Hz phase angle is read directly in tenths of a degree. For a signal of some other frequency in the rated range, the information is read in time units, with resolution up to 0.1 μsec. For all phase measurements, set the phase unit PHASE/PERIOD switch to PHASE, the REFERENCE LEAD/LAG switch to the type of measurement desired, and the counter FUNCTION SELECTOR to PERIOD.

In general, circuit action for a phase measurement is similar to that for a time interval measurement. Trigger circuits in the phase unit supply the pulses which open and close the signal gate in the counter. Arrangement of the circuits will be similar to that shown in figure 5-16 (E), for the time interval measurements.



A SIMPLE WAVEFORM SHOWING TWO POSSIBLE VOLTAGE LEVELS AT WHICH A TIME INTERVAL MEASUREMENT MAY BE STARTED

B TWO POSSIBLE TIME INTERVAL MEASUREMENTS OF A SINGLE COMPLEX WAVEFORM

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Figure 5-17.—Time interval waveforms.

Digital Readout Electronic Counter AN/USM-207

The AN/USM-207 is a portable, solid-state electronic counter for precisely measuring and displaying on a 9-digit numerical readout the frequency and period of a cyclic electrical signal, the frequency ratio of two signals, the time interval between two points on the same or different signals, and the total number of electrical impulses (totalizing). The counter also provides the following types of output signals:

1. Standard signals from 0.1 Hz to 10 MHz decade steps derived from a 1-MHz frequency standard, frequency dividers, and a frequency multiplier.
2. Input signals divided in frequency by factors from 10 to 10^8 by a frequency divider.
3. Digital data of the measurement in four-line binary-coded-decimal form with decimal point and control signals for operation of printers, data recorders, or control devices.
4. A 1-MHz output from a frequency standard.

The AN/USM-207 (figure 5-18) consists of a major counter assembly, two plug-in assemblies

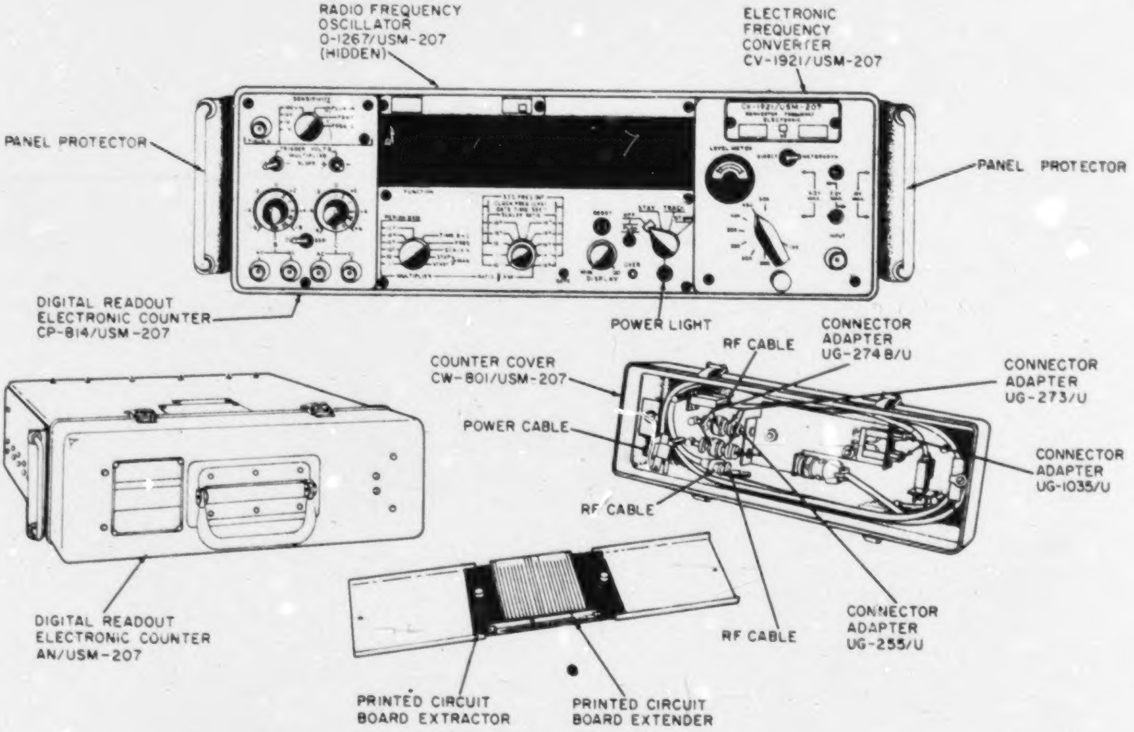
RADIO FREQUENCY OSCILLATOR O-1267/USM-207 (HIDDEN)
ELECTRONIC FREQUENCY CONVERTER CV-1921/USM-207
PANEL PROTECTOR
PANEL PROTECTOR
DIGITAL READOUT ELECTRONIC COUNTER CP-814/USM-207
POWER LIGHT
RF CABLE
CONNECTOR ADAPTER UG-274 B/U
COUNTER COVER CW-801/USM-207
CONNECTOR ADAPTER UG-273/U
POWER CABLE
CONNECTOR ADAPTER UG-1035/U
RF CABLE
DIGITAL READOUT ELECTRONIC COUNTER AN/USM-207
RF CABLE
CONNECTOR ADAPTER UG-255/U
PRINTED CIRCUIT BOARD EXTRACTOR
PRINTED CIRCUIT BOARD EXTENDER

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Figure 5-18.—Digital readout electronic counter AN/USM-207.

which install in recesses on the front and rear panel, and a group of accessory cables and connectors stored in the detachable front cover.

The major assembly Digital Readout Electronic Counter CP-814/USM-207 contains the input amplifiers; gate control; display; reset and transfer control; frequency multipliers; time base dividers; decade and readout boards; numerical display tubes; decimal point and units indicators; power supply and regulator; and controls associated with these circuits.

The Radio Frequency Oscillator O-1267/USM-207 plug-in assembly develops a 1-MHz signal and includes its own power supply. The oscillator includes the 1-MHz output receptacle which may be used as a source of that frequency when the oscillator is connected to a-c power through the basic counter or when connected to the power line independently of the counter. The counter may be operated without the oscillator in totalizing, scaling the input signal, time interval with external clock, and frequency ratio measurements. For other measurements the counter does not require the oscillator when a separate external 100 kHz or 1 MHz signal is connected. In either of these two situations the oscillator may be left in the counter or removed. The oscillator plugs into the right rear of the counter.

The Electronic Frequency Converter CV-1921/USM-207 plug-in assembly permits measurement of frequencies up to 500 MHz using the heterodyne principle. The unit consists of the broadband amplifier, mixer, multiplier, and controls and indicators associated with these circuits. When measurements other than heterodyne frequency measurements are made, the converter is not required, but need not be removed. The converter also permits the measurement of signals from 35 MHz to 100 MHz with a greater sensitivity than available with the basic counter. The converter plugs into the right front of the counter.

Figure 5-19 is the overall functional block diagram of the counter. To make a measurement requires two types of information; a count signal and a gate control signal. These two signals may be generated within the instrument or they may be supplied from outside sources. The type of measurement the counter will make depends upon the relationship of these two signals. In any function the instrument counts the count signal for a period of time determined by the gate control signal. Routing of these signals within the instrument is accomplished by logic circuits. These logic circuits are controlled by means of the front panel controls.

The radiofrequency oscillator (0-1267/USM-207) generates a signal of precise frequency for use throughout the counter or to provide a precise 1 MHz signal for use outside the equipment.

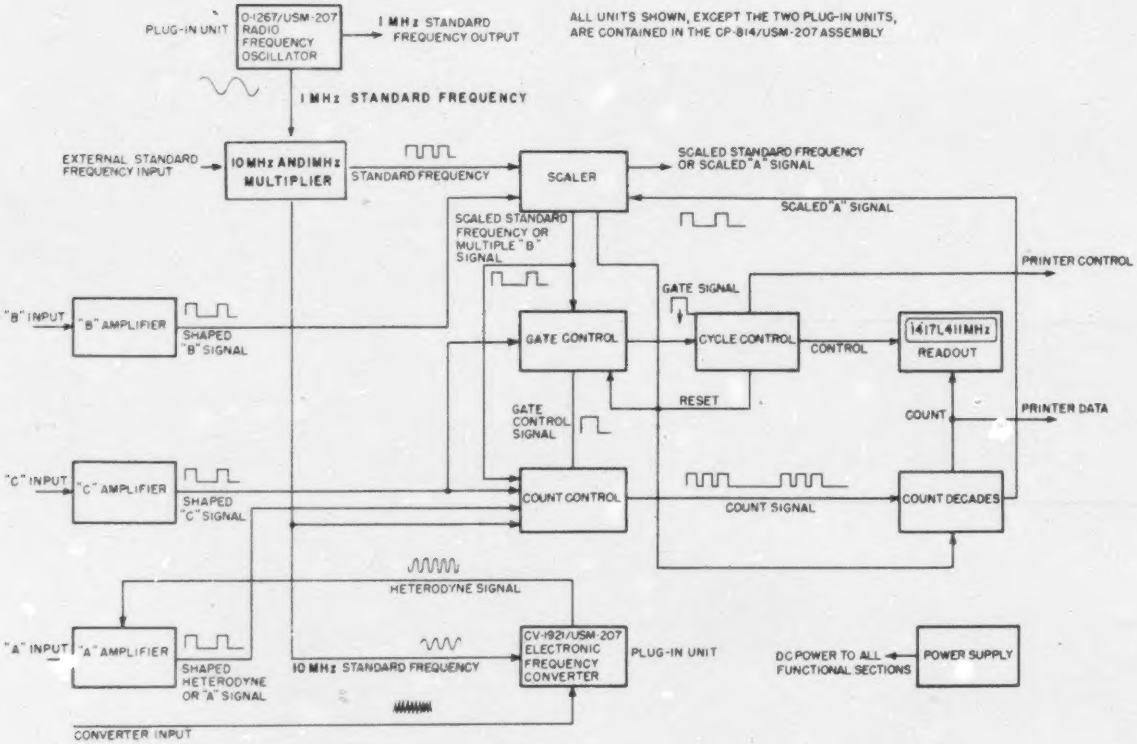
PLUG-IN UNIT
0-1267/USM-207 RADIO FREQUENCY OSCILLATOR
1 MHz STANDARD FREQUENCY OUTPUT
ALL UNITS SHOWN, EXCEPT THE TWO PLUG-IN UNITS, ARE CONTAINED IN THE CP-814/USM-207 ASSEMBLY
1 MHz STANDARD FREQUENCY
EXTERNAL STANDARD FREQUENCY INPUT
10 MHz AND 1 MHz MULTIPLIER
STANDARD FREQUENCY
SCALER
SCALED STANDARD FREQUENCY OR SCALED "A" SIGNAL
SCALED "A" SIGNAL
SCALED STANDARD FREQUENCY OR MULTIPLE "B" SIGNAL
PRINTER CONTROL
GATE SIGNAL
"B" INPUT
"B" AMPLIFIER
SHAPED "B" SIGNAL
GATE CONTROL
CYCLE CONTROL
CONTROL
1417L411MHz
READOUT
RESET
GATE CONTROL SIGNAL
COUNT
PRINTER DATA
"C" INPUT
"C" AMPLIFIER
SHAPED "C" SIGNAL
COUNT CONTROL
COUNT SIGNAL
COUNT DECADES
HETERODYNE SIGNAL
"A" INPUT
"A" AMPLIFIER
SHAPED HETERODYNE OR "A" SIGNAL
10 MHz STANDARD FREQUENCY
CV-1921/USM-207 ELECTRONIC FREQUENCY CONVERTER
PLUG-IN UNIT
DC POWER TO ALL FUNCTIONAL SECTIONS
POWER SUPPLY
CONVERTER INPUT

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Figure 5-19.—Digital readout electronic counter AN/USM-207 overall functional block diagram.

The electronic frequency converter accepts radiofrequencies between 100 MHz and 500 MHz and converts them to radiofrequencies between 5 MHz and 100 MHz for measurement by the basic counter.

The "A" amplifier amplifies the A input signal or the output of the converter for use throughout the counter.

The "B" amplifier amplifies and shapes the B input signal for use throughout the counter.

The "C" amplifier amplifies and shapes the C input signal for use throughout the counter.

The 10 MHz and 1 MHz multiplier multiplies the frequency and shapes the signal generated by the radiofrequency oscillator. It also provides precise timing signals to the various functional sections of the basic counter and to the frequency converter.

The scaler consists of a series of decade dividers and gating systems which provide divided standard frequencies and control signals depending on the type of measurement the instrument is making.

The gate control generates the gate control signal. This signal determines the length of time that the count decades will count the count signal.

The count control provides the proper count signal to the count decades, as selected by the setting of the front-panel switches.

The cycle control produces all signals necessary to display the measurement results on the readout and to recycle the counter.

The count decades count the count signal when permitted to do so by the gate control. The result of their counting becomes the final reading displayed by the readout at the end of each measurement.

The readout receives binary-coded-decimal (BCD) data from the count decades, decodes this data into decimal form and drives the readout indicator tubes. The readout also contains memory circuits which function when the counter is operated in the "Store" mode.

The power supply supplies all d-c power required by the basic instrument and the converters and consists of seven d-c supplies. Five of these supplies (+18 volt, +12 volt, +6 volt, and −12 volt) are regulated and two (+180 volt and +45 volt) are unregulated.

COMPONENT TESTERS

This section discusses the testing of components considered to be most essential in any electronic circuit. These components include the transistor, crystal diode, and the electron tube. During the process of maintaining the equipment for which the technician is responsible, these three particular components are the ones with which he becomes most involved.

ELECTRON TUBE TESTER

Before discussing the testing of electron tubes on the tube tester, the substitution method of testing is described.

Substitution of a tube known to be good is a simple and reliable method of determining the quality of a questionable tube. Usually this method cannot be used to eliminate more than one tube in a single circuit. For instance, if both an RF amplifier and an IF amplifier are defective in a receiver, replacing either one does not correct the trouble. Also the practice of replacing several tubes in a circuit, all at one time, will usually result in misalinement of a tuned circuit. Under conditions such as these, the use of test equipment designed for testing the quality of a tube saves valuable time.

Experience has shown that tube failures may be roughly classified as follows: mechanical defects and gas within the tube, filament (or heater) burned out, change in tube characteristics, physical damage, and intermittent shorts. Mechanical defects and rise of gas pressure within the tubes are attributed to faulty construction and processing. Some of these defects cannot be detected by standard testing methods until the tubes have been in operation for some time. Filament burnout may be caused by repeated sudden application of full voltage to the filament. Initial heating of the filament is nonuniform. As a result, mechanical stresses due to thermal expansion are set up, and these stresses weaken the filament structure and hasten its failure.

Change in tube characteristics is a broad classification and covers decreasing emission, change in cutoff voltage, changing transconductance, etc. Such changes are usually the

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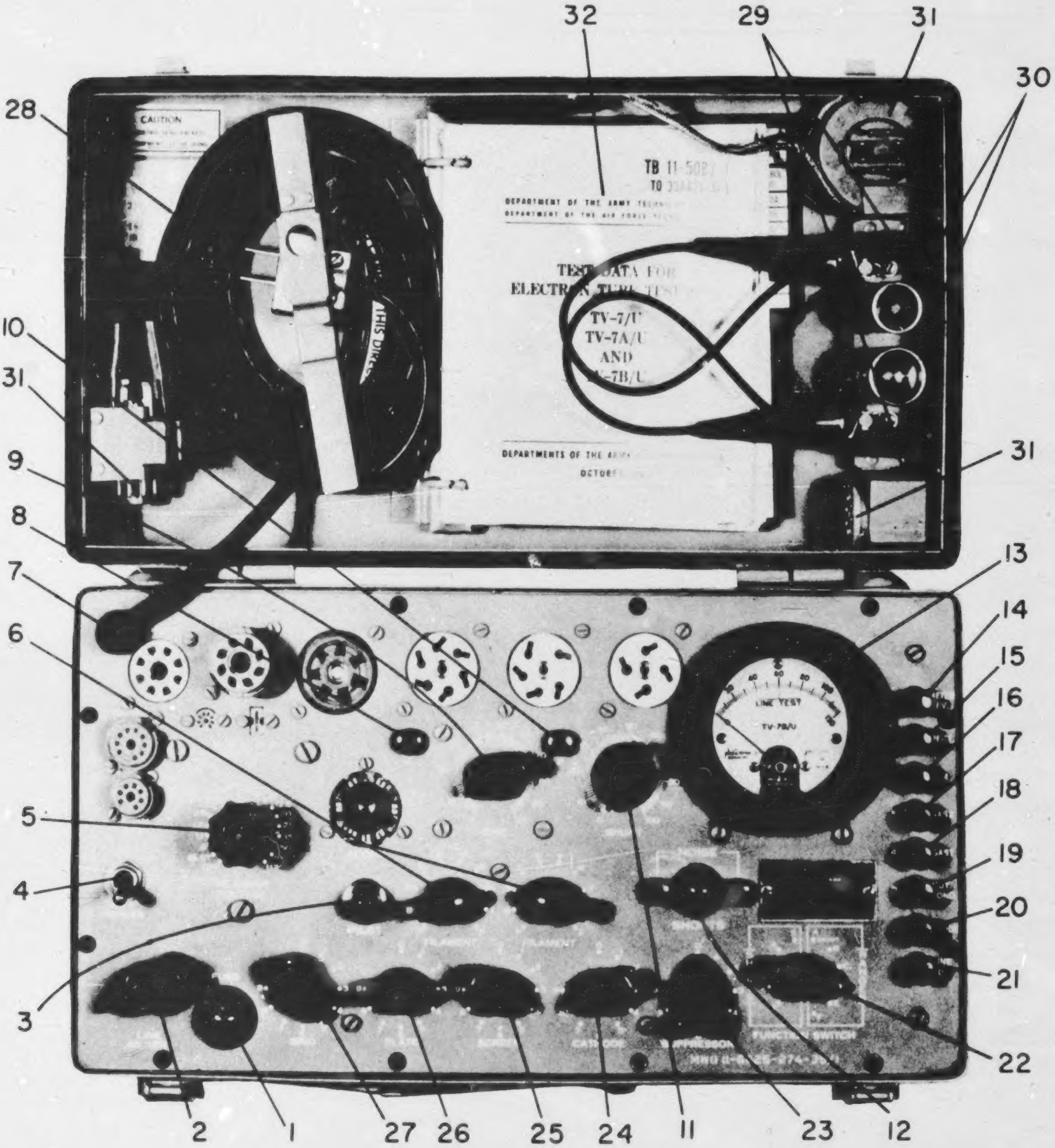
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23
12
CAUTION
TB 11-5027
TEST DATA FOR
ELECTRON TUBE TESTERS
TV-7/U
TV-7A/U
AND
TV-7B/U
LINE TEST
TV-7B/U
CATHODE
SUPPRESSOR
FUNCTION SWITCH

AT.105

Figure 5-20.—Electron Tube Test Set TV-7/U

result of deterioration of the cathode structure, or formation of a cathode interface surface in the tube or changes in alinement of the electrode parts. Physical damage is largely accidental. It includes such causes as breakage, bending of pins, and inadvertent application of excessive voltages. Intermittent shorts are caused mainly by foreign matter, such as lint within the tube assembly.

Operation of a Typical Tube Tester

The tube-testing equipment discussed in this section is a typical, general-purpose test equipment of the transconductance type. The TV-7/U tube tester (fig. 5-20) is representative of this type equipment.

The front-panel controls on this tester adjust (or switch) the various potentials necessary for the testing of tubes. The tube data chart (booktype) which is supplied with the equipment, lists the control setting for the various types of tubes generally encountered in the field.

CAUTION: Before the tube to be tested is inserted in the correct test socket, make certain that the front-panel controls are set to the positions listed for that type tube in the data chart. This precaution is necessary to prevent excessive voltage from being applied to the tube elements (especially the filament).

LINE VOLTAGE ADJUSTMENT AND TEST.–The line voltage adjustment is necessary so that the line voltage applied to the primary of the transformer can be preset to an operating value. A 93-volt potential is used as a test reference point, regardless of the variations caused by different tube loads or fluctuations in the a-c supply. Applied voltages may range from 105 to 130 volts and still be adjustable. Depressing the LINE TEST button connects the meter of the tube tester to read the "B" supply voltage. The test equipment is calibrated at the factory so that the meter pointer is approximately centered when the voltage across the primary is 93 volts. Since various types of electron tubes draw different values of currents, a LINE ADJUSTMENT rheostat (connected in series with the primary) is provided. The primary voltage can thus be set to the designed operating voltage before any test is begun. A small protective lamp which will burn out on overload is connected in series with the primary of the transformer to prevent equipment damage.

SHORT CIRCUIT AND NOISE TEST.–It is very important that the technician apply the test for short-circuited elements to a tube of doubtful quality before any other tests are made. This procedure protects the meter (or any other indicator) from damage. Also it follows logically

Nomenclature for figure 5-20.

1. Fuse lamp.
2. Line adj. control.
3. Pilot light.
4. Power switch.
5. Filament voltage.
6. Filament selectors.
7. A-c line cords.
8. Grid jack.
9. Bias control.
10. Plate jack.
11. Shunt control.
12. Neon lamp.
13. Meter.
14. Meter reverse switch.
15. Rectifier switch.
16. OZ4 switch.
17. Gas 2 switch.
18. Gas 1 switch.
19. Mut. Cond. switch.
20. Diode switch.
21. Line adj. switch.
22. Function switch.
23. Suppressor selector.
24. Cathode selector.
25. Screen selector.
26. Plate selector.
27. Grid selector.
28. Power cord.
29. Test leads.
30. Pin straighteners.
31. Adapter.
32. Test data book.

that, if a tube under test has elements which are short-circuited, there is no further need to apply additional tests to that tube. Short-circuit tests are usually sensitive enough to indicate leakage resistance less than about one-fourth megohm. The proper heater voltage is applied so that any tube elements which might short as a result of the heating process will be detected. The short-circuit test is similar to the test used to detect noisy (microphonic) tubes caused by loose elements. Since the only difference between the two tests is in the sensitivity of the device used as an indicator, the noise test is discussed as part of the short-circuit test.

Figure 5-21 shows a basic circuit used for detecting shorted elements within a tube. With the switch set to position 2 as shown, the plate of the tube under test is connected to the leg of the transformer secondary containing the neon lamp. All the other elements are connected through switches to the other leg of the secondary. If the plate element of the tube is touching any other element within the tube, the a-c circuit of the secondary is completed and as a result, both plates of the neon lamp glow. If no short exists, only one plate of the neon lamp will glow. Each of the other elements is tested by means of the switching arrangement shown. Resistor R2 limits the current through the neon lamp to a safe value. Resistor R1 bypasses any small alternating currents in the circuit which might be caused by stray capacitance and thus prevents the neon lamp from indicating erroneously. Tapping the tube lightly is recommended to detect loose elements which might touch when the tube is vibrated.

By means of the function switch the electrodes of the tube under test are switched in turn across a neon SHORTS lamp, which is connected in series with the secondary of the transformer. Shorted tube elements (and any other internal tube connections) complete the a-c circuit, causing both plates of the neon lamp to glow. Momentary flashes of the neon SHORTS lamp may be caused when the switch is rotated. These flashes are caused by the charging of the small inter-electrode capacitances of the tube when the voltage is applied, and do not indicate short circuits. If the tube under test has a shorted element, the neon lamp will glow continually on one or more switch positions. Since the filament circuit and other internal tube connections will show up as short circuits in this test, the tube data chart should be consulted for pin connection information before interpreting the results of the test.

The noise test is used to check for intermittent shorts or microphonic noise. The circuit used is the same as that employed for the short-circuit test. In tests for noise, the antenna and ground terminals of a radio receiver are connected to the NOISE TEST receptacles. Any

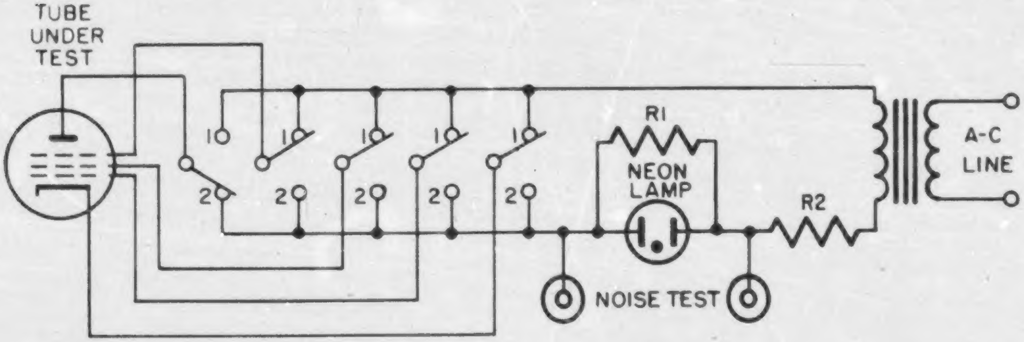


Figure 5-21.—Basic circuit used for short circuit and noise tests.

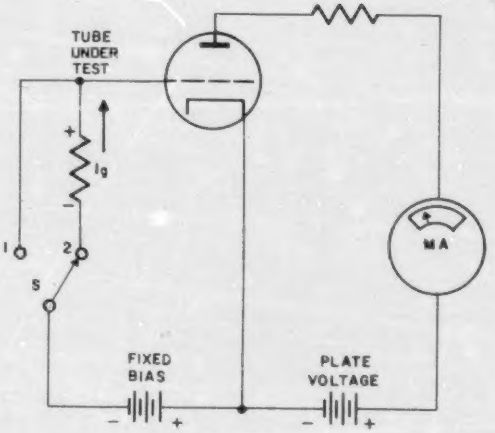
intermittent short between tube electrodes permits the a-c voltage from the power transformer to be applied momentarily to the neon lamp.

The brief oscillation of this lamp contains various radiofrequencies which are reproduced as audible signals in the receiver speaker. A less sensitive noise test can be made using a pair of headphones instead of the radio receiver. The tube should be tapped while it is being tested.

GAS TEST.—In all electron tubes, except some types of rectifier tubes and thyratrons, the presence of any appreciable amount of gas is extremely undesirable. When gas is present, the electrons emitted by the cathode collide with the molecules of gas. As a result of these collisions, electrons (secondarily emitted) are dislodged from the gas molecules, and positive gas ions are formed. These ions are attracted by (and cluster around) the control grid of the tube, because it is negative (bias) and absorbs electrons from the grid circuit in order to revert to the more stable gas molecules (not ionized). If the amount of gas in the tube is appreciable, the collisions between the numerous gas molecules and the cathode-emitted electrons release many secondarily emitted electrons, and the resulting flow of grid current is high.

The basic circuit used for the gas test is shown in figure 5-22. With switch S set to position 1, a certain value of plate current is measured by the d-c milliammeter. If there is no gas (or a negligible amount) present in the tube, setting switch S to position 2 does not change the plate current reading. If gas is present, current flows through the grid resistor (large value), causing a voltage drop to develop with the polarity as shown. The net effect is to reduce the negative bias voltage on the grid of the tube resulting in an increase of plate current. Small plate current increases are normal; large increases indicate excessive gas.

The value of the grid resistor used in the typical tube tester is 180,000 ohms. Two push-button switches, labeled GAS No. 1 and GAS No. 2, are used for gas test. GAS No. 1 button is first depressed and the plate current reading on the meter is noted. Depressing the button marked GAS No. 2 inserts the 180,000-ohm resistor into the grid circuit. If gas is present in the tube, the grid current that flows reduces the normal bias on the tube and increases the plate current measured by the meter. A tube with a negligible amount of gas produces an increase in plate current of less than one scale division when GAS No. 2 button is depressed. An increase of more than one scale division indicates an excessive amount of gas in the tube.



AT.107

Figure 5-22.—Basic circuit used for gas test.

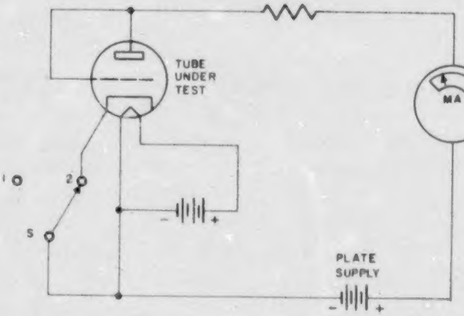
CATHODE LEAKAGE TEST.—The cathode element of an electron tube is essential because it supplies the electrons necessary for tube operation. Electrons are released from the cathode by means of some form of energy—generally heat—which is applied to it. An indirectly heated cathode consists of a heater wire (usually a tungsten alloy) enclosed in, but insulated from, a metal sleeve (nickel). This sleeve is coated with an electron emitting material (usually strontium or barium compounds) on its outer surface, and is heated by radiation and conduction from the heater. Useful emission does not take place from the heater wire.

When a tube which uses an indirectly heated cathode develops noise, it is almost a certain indication that a leakage path is present between the cathode sleeve and the heater wire. This assumption is justified because in the design of a tube the heater must be placed as close as possible to the cathode so that maximum tube efficiency is attained. Continual heating and cooling of the tube structure may cause small amounts of the insulation between the cathode and heater to become brittle or deteriorate, leaving a high resistance leakage path between these elements. Under extreme conditions the insulation may shift enough to allow actual contact of the elements. Since the heater and cathode are seldom at the same potential, any form of leakage causes noise to develop in the tube.

The cathode normally is maintained at a higher positive potential, because cathode bias is the most common type of bias utilized. The heater circuit is usually grounded to chassis, either on one side of the filament supply or by a center-tap arrangement. Therefore, if a resistance path is present, a leakage current may flow from the heater to the cathode. Thus, in effect the cathode functions in the same manner as the plate of a tube; that is, it receives electrons. Assuming the existence of a high-resistance short, the current flow from the heater to the cathode will vary with any vibration of the tube because vibration varies the amount of resistance. If the cathode and heater are completely shorted (zero ohms), it is impossible for the tube to develop any cathode bias.

A cathode leakage test is sometimes made while a tube is being tested for short-circuited elements or noise. However, some tube-testing instruments incorporate the cathode leakage test as an additional test which is not part of the short-circuit test. Figure 5-23 shows a basic circuit which is used to detect leakage between the heater and cathode elements of a tube. With switch S set to position 2, a certain value of plate current flows.

When switch S is set to position 1, the cathode becomes a floating element; if no leakage path is present, the plate current should fall to zero. If the elements are completely shorted, the plate current reading remains the same as the initial reading (switch S in position 2); if they are only partially shorted, a plate current less than normal but greater than zero is indicated.



AT.108

Figure 5-23.—Basic circuit used for cathode leakage test.

FILAMENT ACTIVITY TEST.—The filament activity test is used to determine the approximate remaining life of an electron tube insofar as the longevity of the cathode emitter is concerned. The test is based on the principle that the cathode in almost all electron tubes is so constructed that a decrease of 10 percent of the rated heater voltage causes no appreciable decrease in emission.

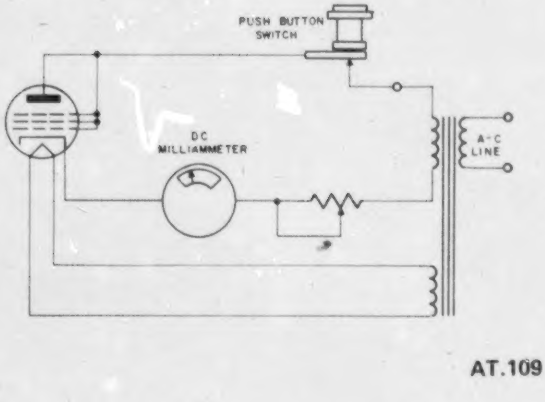
On a tube-testing equipment incorporating this test there is a two-position switch (FILAMENT ACTIVITY TEST) which has one position marked NORMAL and the other marked TEST. The switch remains in the NORMAL position for all tests other than the filament activity test. When the switch is set to the TEST position, the filament (or heater) voltage which is applied to the tube under test is reduced by 10 percent.

The filament activity test is performed as follows: After the quality test is made, the TUBE TEST button is held depressed, and the filament activity test switch is set to TEST position. If the indicator shows a decreased reading after a reasonable time is allowed for the cathode to cool, the useful life of the tube is nearing its end.

RECTIFIER TEST.–The circuit used for testing full-wave rectifiers, diodes, and 0Z4 tubes is an emission test circuit which is similar to the basic circuit shown in figure 5-24. An a-c voltage of defininte value is applied to the tube under test, and the meter indicates the rectified plate current. The two sections of a full-wave rectifier are tested separately.

The button for testing OZ4 cold-cathode rectifier tubes provides a higher a-c voltage than is normally used for heater (or filament) type rectifiers. The button for diode tubes provides a lower voltage than that used for regular rectifiers, and also inserts a protective series resistance.

QUALITY TEST.–For the quality test, the d-c grid bias for the tube under test is supplied by a rectifier tube. The correct value of this grid bias is obtained when the bias control is rotated to the setting listed in the test data chart for the tube being testd. An a-c voltage (4.7 volts rms), which is taken from a separate winding on the power transformer, is applied in series with the grid bias. This voltage causes the grid to deviate in positive and negative directions from the d-c bias level, thereby effecting the grid-voltage change (ΔE_g) required for a dynamic transconductance test. The plate voltage of the tube under test is supplied by a rectifier tube. The meter which indicates the plate current change (ΔI_p) is in the return circuit of the rectifier supply. The meter indicates the tube condition in arbitrary numerical units from 0 to 120. The tube test data book, mounted inside the cover of the equipment, lists the minimum numerical value of meter reading for satisfactory performance. Tubes reading below this value are not considered suitable for use in military equipment. The shunt control is used to control the sensitivity of the meter. Setting of the dial is required only when the function switch is in the RANGE (A) SHUNT position. The setting for this switch is determined by the type of tube being tested and is listed in the tube data chart.



AT.109

Figure 5-24.–Basic circuit used for emission test.

SEMICONDUCTOR TESTERS

Since semiconductors have replaced vacuum tubes in many new equipments, the testing of semiconductors has become increasingly vital. Two basic types of equipment are discussed in this section. They are the crystal diode tester and the in-circuit transistor tester, represented by the TS-1100/U.

Microwave Crystal Test Set

Microwave Crystal Test Set, Type 390 (fig. 5-25) is used to provide an accurate and reliable indication of the quality of mixer crystals. Its accuracy is comparable to that of more elaborate laboratory test setups, but its testing versatility is more limited.

The quality of a microwave crystal can be determined by measurement of its conversion loss and noise temperature. The Type 390 is designed specifically to perform these tests on crystals intended for use at frequencies of 10,000 MHz and lower. For crystals used at frequencies above that figure, the readings are relative–crystals can still be selected in the order to comparative quality.

Conversion loss is defined as the ratio of the power available from the RF signal source to the power available at the IF output of the mixer. Noise temperature is defined as the ratio of the IF noise power available from the crystal to the thermal noise power available from a resistance

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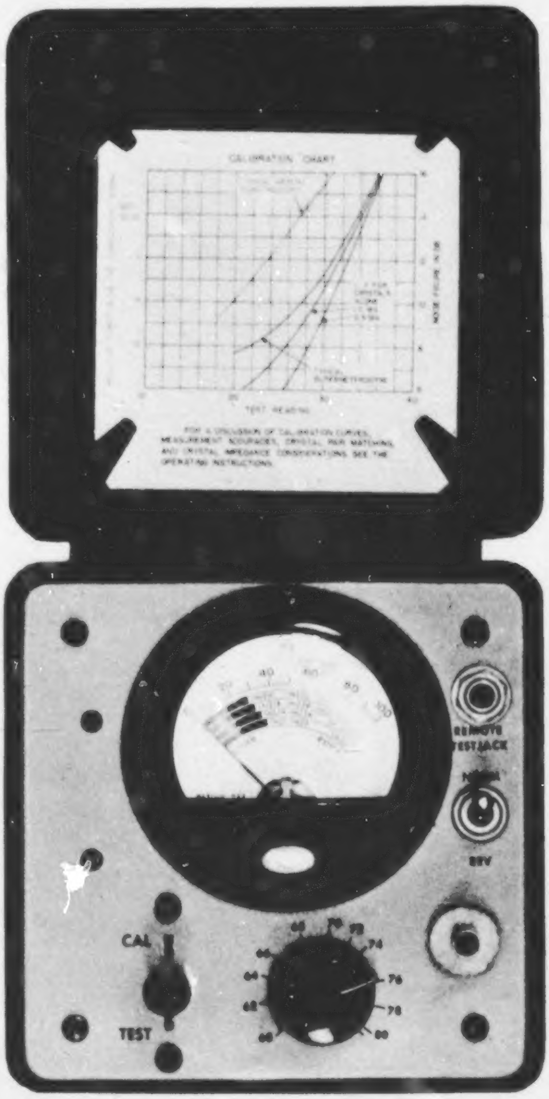


AT.111

Figure 5-25.—Type 390 microwave crystal checker.

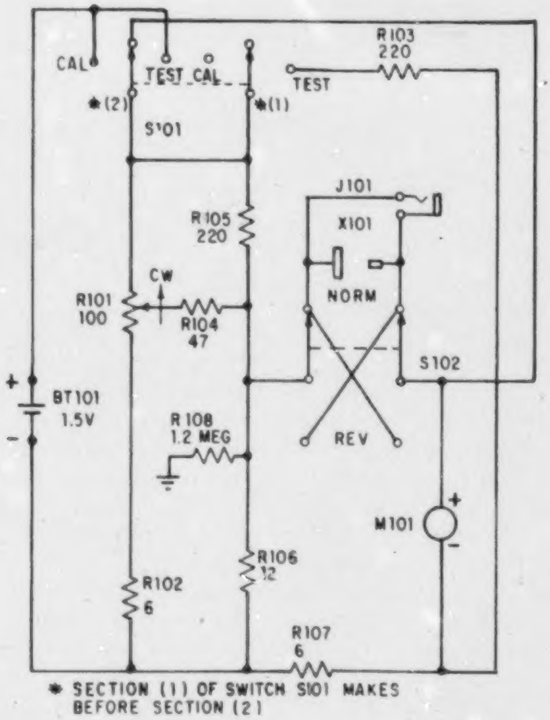
(equal to the RF resistance of the crystal) at room temperature. The theory of the mixer crystal test set is based on the fact that the minimum conversion loss and noise temperature can be determined from the degree of nonlinearity of the static voltage-current (E-I) curve of a mixer crystal.

The Type 390 measures this nonlinearity by measuring the incremental change in crystal current (Δi) caused by an incremental change in voltage (Δe) applied to the crystal in the "forward" direction. Adjustment is made to the variable resistor R101 with the CAL-TEST switch in the CAL position. (See fig. 5-26.) If the E-I curve of the crystal under test were linear, a midscale reading would be obtained on meter M101 when S101 was switched to the TEST position. If the reading actually obtained is below midscale, the E-I curve of the crystal is nonlinear. The amount by which the reading falls below the midscale point is a measure of the degree of the crystal's nonlinearity. The lower the meter reading below midscale, the more nonlinear the E-I curve for that crystal, and the lower its conversion loss and noise temperature.

Figure 5-26 is a schematic diagram of the test set. The initial adjustment of voltage V_i is made using variable resistor R101 with the CAL-TEST switch S101 in the CAL position. (An incorrect adjustment of R101 may apply excessive voltage to M101, causing damage to the pointer. For this reason, R101 should always be set fully clockwise before switching to the CAL position). Also, see figure 5-25.

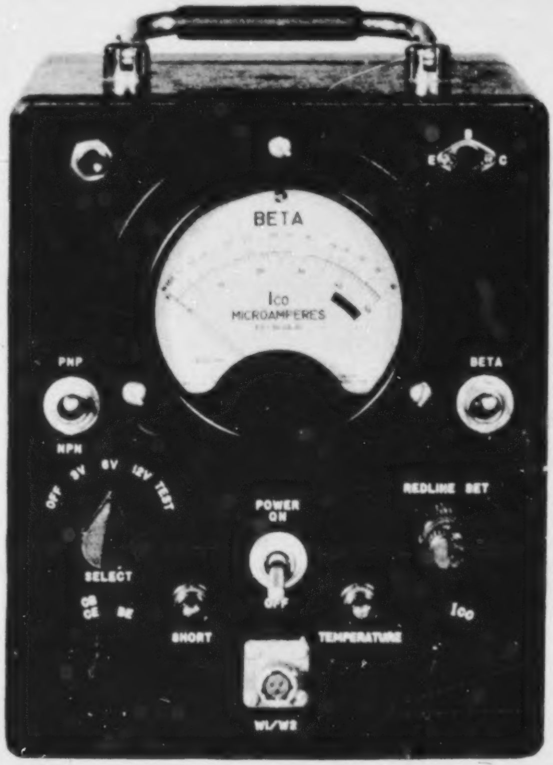
Fixed resistors R102, R104, R105, and R106 determine the limits to which V_i can be adjusted. The voltage increment (Δe) is established by R103 and R107 when in the TEST position; it has the same value for all crystals.

When a crystal is to be tested, it is placed in crystal holder X101. The crystal should always be handled by the base; while inserting the crystal, any static charge should be removed by touching the base to the grounding spring on the holder. The switch is set to the CAL position, and R101 is adjusted until the meter indication coincides with the calibration scale reading of R101. When S101 is moved to the TEST position, M101 indicates the quality of the


CAL
TEST CAL
TEST
R103
220
*(2)
*(1)
S101
J101
X101
R105
220
CW
R101
100
R104
47
NORM
S102
+
BT101
1.5V
-
R108
1.2 MEG
REV
M101
+
-
R106
12
R102
6
R107
6
* SECTION (1) OF SWITCH S101 MAKES BEFORE SECTION (2)

AT.110

Figure 5-26.—Microwave Crystal Test Set, Type 390, schematic diagram.


E
B
C
BETA
Ico
MICROAMPERES
PNP
NPN
BETA
OFF
3V
6V
12V
TEST
SELECT
CB
CE
BE
POWER ON
OFF
REDLINE SET
SHORT
TEMPERATURE
Ico
W1/W2

AT.112

Figure 5-27.—Test Set, Transistor TS-1100/U.

crystal. With the aid of a chart supplied with the test set, the reading of M101 can be converted to the actual conversion loss and noise temperature. Block sections on the meter scale help ease the acceptance or rejection of crystals according to the type being tested.

The purpose of the NORM/REV switch (S-102) is to provide the correct bias-voltage polarity for the crystal diode being tested; and to determine the polarity of a crystal diode when it is not known or when the crystal diode is located remotely from the test set.

In-Circuit Transistor Checkers

Test Set, Transistor TS-1100/U (fig. 5-27) is designed to measure the beta parameter of a transistor when the transistor is connected in a circuit, and to measure beta and I_{co} parameters with the transistor removed from the circuit.

The characteristics of the test set are:

1. Range of beta 10 to ∞ in a single band.
2. Leakage current measurements: 0 to 50 microamperes.
3. Temperature range: 0° C to + 50° C.
4. Power Supply: Battery operated.

The equipment contains two separate battery power supplies. One provides the power for the internal circuits, and the other furnishes the bias voltage required for the transistor under test. Either the mercury type or zinc-carbon batteries may be used for operation of the test set.

Low impedance techniques are used for measurement to isolate the transistor under test from the surrounding circuitry. The measurement accuracy of the tester is within ±20 percent provided that the loading of the emitter-base diode or the collector-base diode is not below 500 ohms, and the loading between the collector and the emitter is not below 500 ohms. If the emitter-base load contains a diode, the series impedance should not fall below 7,000 ohms to maintain this accuracy.

With the use of an appropriate shorting technique, the accuracy can be improved. The shorting technique consists of connecting a jumper wire between the emitter of the transistor under test and the far side of all components connected to the base electrode of the transistor. This technique is not universally applicable, and it should be employed only by skilled personnel.

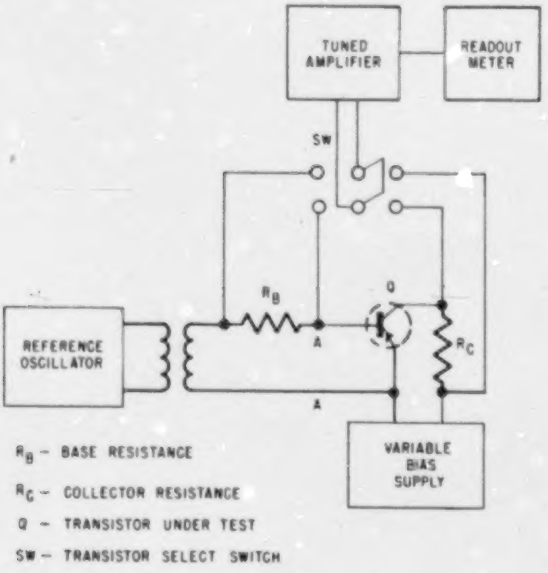
The range of beta that can be measured is between 10 and ∞. A beta of infinity (∞) corresponds to zero microamperes on the readout meter scale. A transistor having a beta below 10 will cause the pointer of the meter on the tester to move off the scale. Because of the nonlinear characteristic of the meter scale, which causes crowding at the high end, the readout accuracy for betas above 100 is impaired.

The following controls, as seen on the front panel (fig. 5-27), are incorporated in the test set:

1. POWER switch (labeled ON-OFF): Turns the internal power source on or off.
2. PNP-NPN (Transistor select) switch: Selects proper collector bias polarity for the type transistor under test.
3. BETA switch: Permits readout of beta.
4. BIAS SELECT switch: Used to set proper collector bias voltages (nominally 3, 6, or 12 volts). Also checks the condition of internal battery when in the TEST position.
5. RED LINE SET control: Adjusts the amplitude of the test signal.
6. SHORT switch (labeled CB, CE, BE): Enables measurement of a short circuit or a low impedance in the collector-base (CB), collector-emitter (CE), or base-emitter (BE) circuits.
7. I_{co} switch: Enables readout of transistor leakage.
8. SHORT indicator: The indicator lamp will light when a short circuit or low impedance exists in either the transistor under test or in the surrounding circuitry. If the lamp lights, this indicates a load of less than 500 ohms.
9. TEMPERATURE indicator: The indicator lamp will light when the ambient temperature surrounding the equipment exceeds +50°C. This indicates that the equipment is operating in an environment beyond that for which it has been designed, and that measurement inaccuracies will arise.
10. METER: Indicates magnitude of beta; indicates magnitude of I_{co}; and indicates the condition of the internal battery. (The battery is good when the meter needle moves under the green band on the dial.)
11. PROBE connector: For connecting the cables (furnished with the test set) to the transistor to be tested.
12. TRANSISTOR socket (labeled E-B-C): Enables direct connection between the test set and transistor to be tested.
13. BATTERY DISCONNECT switch (upper left corner of panel—not labeled): Disconnects the internal battery when the front cover is snapped in place.

FUNCTIONAL DESCRIPTION.—The block diagram (fig. 5-28) consists essentially of a reference oscillator, a tuned amplifier, and a variable bias supply. The oscillator is used to generate a test signal, the tuned amplifier is used to measure the second harmonic component of the current of the transistor under test, and the bias circuit furnishes the appropriate voltages to the transistor under test.

The reference signal source is a Hartley oscillator operating at a frequency of 1,125 Hz. The transistor under test is biased for approximately class B operation. Thus, the transistor conducts only when the input signal level exceeds the work function of the emitter-base diode. The input signal is adjusted until the average collector current is 1 milliampere. The current passes through the collector load resistor, and a voltage is developed across it. This signal is first coupled through a high gain, narrowband amplifier, having a center frequency of 2,250 Hz, and then through a d-c microammeter. The amplifier gain has been adjusted so that the red line on the meter face corresponds



AT.113

Figure 5-28.–TS-1100/U, block diagram.

to an average collector current of 1 milliampere.

The bandpass amplifier and meter are then switched across the base load resistor, and the meter then reads the magnitude of the average beta directly for a given transistor. Since the collector current is held constant for all transistors under test, the base current is inversely proportional to beta.

Direct measurement of the average collector and base current cannot be made on a d-c meter placed in series with these electrodes. This is because of the large errors which may result from the presence of "sneak paths" provided by the external network, since it is possible to have a direct current flow in these paths from the collector bias supply.

By making an a-c measurement, the problems of erroneous direct current are eliminated, but others are introduced. If the a-c components of the collector current and base current were measured without filtering, the readout meter would not be able to differentiate between the normally rectified signal of the transistor and a nonrectified signal caused by the a-c sneak paths. To eliminate these erroneous signals, the second harmonic component of the signal current is measured.

Octopus

The octopus is an electronic device used to troubleshoot deenergized printed circuit boards. It is designed for local construction and to locate defective components of printed boards quickly and safely without the necessity of removing component leads from the circuit. This will result in a savings in maintenance manhours and eliminates the possibility of damage caused by soldering iron heat. Used in conjunction with any standard oscilloscope, the octopus affords a visual display of component condition.

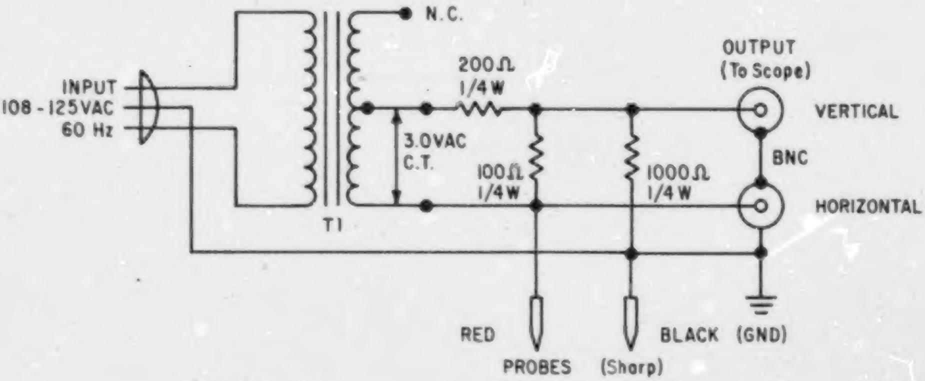
The octopus, specifically designed to quickly test delicate components, does not deliver more than 1.0 milliampere of a-c; also, it energizes components during test, without removal of circuit interconnections much the same as they are energized in circuit during normal service.

While the octopus tests all components for shorts and opens, it can also be used to check front to back ratios on junction components (transistors and diodes). Moreover, utilizing Lissajous and combination patterns on the oscilloscope, the octopus easily analyzes integrated circuits and reactive components (capacitors and inductors) that defy ohmmeter analysis. It is useful also in checking circuit continuity (switches, fuses, lamps, printed wiring, etc.) and high-resistance solder joints.

As shown in figure 5-29, the few parts that go into the construction of the octopus are all common items. For this reason, and since all the parts are noncritical, they may be replaced by whatever suitable parts are locally available.

Low voltage and low current are necessary for protection of delicate components; the 1,000 ohm resistor placed across 1.0 volt assures the safe current of 1.0 milliampere. A center tapped 6.3 volt filament transformer (T1) is commonly used. It delivers about 3.0 volts a.c. (from center tap), which is dropped by resistors to 1.0 volt.

The leads should be color coded (black for the ground and red for the hot lead) and should be needle tipped or filed to a sharp point to


N.C.
OUTPUT (To Scope)
200Ω 1/4W
INPUT 108-125VAC 60 Hz
VERTICAL
3.0VAC C.T.
BNC
100Ω 1/4W
1000Ω 1/4W
HORIZONTAL
T1
RED
BLACK (GND)
PROBES (Sharp)

AQ.595

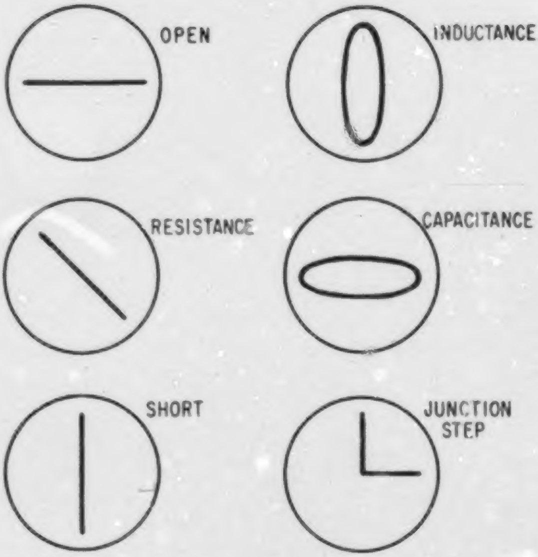
Figure 5-29.—Octopus.

penetrate the plastic and moisture-fungus-proof coating on some printed circuit boards. Dull leads usually fail to make proper contact. To prevent lead hunting, the leads should be permanently attached to the octopus. BNC connector jacks are used for the vertical and horizontal outputs or the cables may be permanently fastened.

A fuse, on/off switch, and indicating neon bulb may be added to the primary circuit if desired.

APPLICATION.—Since each basic component being tested projects a different display, the octopus operation is the utmost in simplicity. Figure 5-30 illustrates the most common displays on the oscilloscope.

When the tester is to be used, its vertical output is connected to the oscilloscope's vertical input and its horizontal output to the oscilloscope's horizontal input. The vertical and horizontal gain controls on the oscilloscope should be adjusted to prevent trace ends from going off the scope. Standard operational procedure for any board being tested for shorts requires that the power be removed. If the printed circuit board or chassis under test is


OPEN
INDUCTANCE
RESISTANCE
CAPACITANCE
SHORT
JUNCTION STEP

AQ.596

Figure 5-30.—Typical oscilloscope displays.

grounded, the black lead should be attached to the ground end of the components.

Because the octopus is an a-c device, the technician is able to observe reactive components and Lissajous and front-to-back ratios of junction components. It is therefore unnecessary to reverse the leads. When observing transistors, check first from the base to one side and then from the base to the other side. A collector-to-emitter test would have to pass through two junctions in series and therefore usually does not produce a usable result. An ideal single junction check will produce a 90° step display, indicating a very high front-to-back ratio. This means an open in the reverse direction and a short in the forward direction. A display that is open more than 90° is something less than perfect. The wider the angle, the less the merit of the junction. Refer to figure 5-31.

For the technician to become proficient in testing components in circuit, it is only necessary for him to recognize the combination patterns arising from grouped components. If the diode and capacitor shown in figure 5-32 were under test, the display shown in that figure would be the result. The oscilloscope presents both a Lissajous (X_C reactance) and a 90° junction step, informing us that the components are neither shorted nor open.

If the transistor circuit shown in figure 5-33 were under test (base to emitter), the trace shown would result. The scope pattern comprises both a junction step and a Lissajous, again informing us that the components are neither shorted nor open. Because of the coil resistance, the junction step appears to be greater than 90° in fact, approximately 120°. This is common in any circuit that contains resistance in parallel with a junction component.

If the transistor in figure 5-34 contained an electrical short between the base and collector, the display shown would result during testing from the base to the collector.

To check a potentiometer for noise, connect one probe to the pot arm and the other probe to either end, then manipulate the pot through its

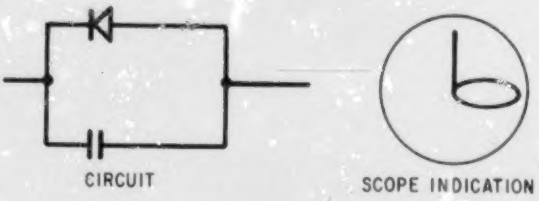


Figure 5-32.–Diode check.

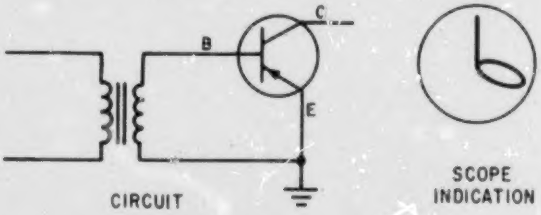


Figure 5-33.–Transistor check, base to emitter.

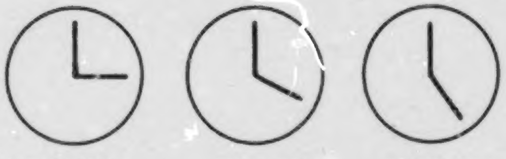
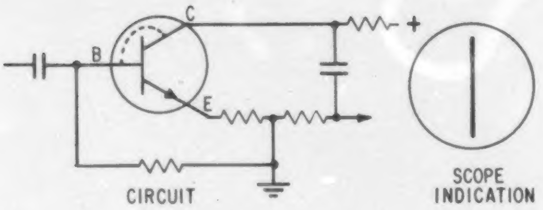
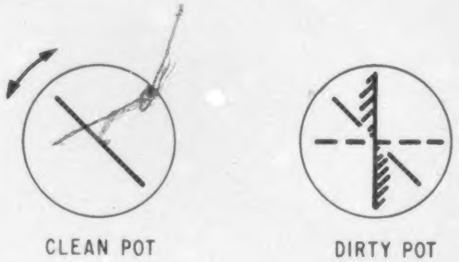


Figure 5-31.–Transistor check, single junction.



AQ. 600

Figure 5-34.—Transistor check, bass to collector.



AQ. 601

Figure 5.35.—Potentiometer noise check.

range while observing the oscilloscope pattern. Refer to figure 5-35.

To distinguish NPN from PNP transistors, move the red probe to the transistor base and the black lead to either the emitter or collector. If the step pattern opens downward, the transistor is NPN; if the pattern opens upward, the transistor is PNP. The same techniques can also be used to determine diode direction.

Occasionally it may appear necessary to desolder a part to determine its condition. It has been found that in such instances a comparison check with a known good board does away with the need to desolder the suspect component. This comparison method, which gives conclusive results, is recommended whenever there is any question regarding a component's operating condition.

Very small value capacitors will appear open rather than reactive, and very small inductors will appear shorted rather than reactive. In most cases, however, this is immaterial, since it is still possible to detect a shorted capacitor and any open inductors. Obviously an ohmmeter could do no better than the octopus on such components. There is, however, a method for regaining the active Lissajous for observation of these small components when that is desired; merely increase the gain adjustments on the oscilloscope to the desired amplification. Remember, of course, to return the gain settings to normal before checking other components.

Nomenclature for figure 5-36.

1. **Dissipation limiting resistor.**
2. **Peak volts control.**
3. **Polarity switch.**
4. **Peak volts range.**
5. **Focus control.**
6. **Intensity control.**
7. **Astigmatism control.**
8. **Scale illumination.**
9. **Vertical/horizontal select.**
10. **Display position.**
11. **Amplifier calibration.**
12. **Steps/sec selector.**
13. **Polarity switch.**
14. **Steps/family.**
15. **Repetitive/single family.**
16. **Step selector.**
17. **Series resistor.**
18. **Step zero.**
19. **Zero current/voltage.**
20. **Indicator lamp.**
21. **Power ON-OFF.**
22. **Binding posts B.**
23. **Socket B.**
24. **Configuration switch.**
25. **Socket A.**
26. **Binding posts A.**
27. **Comparison switch.**

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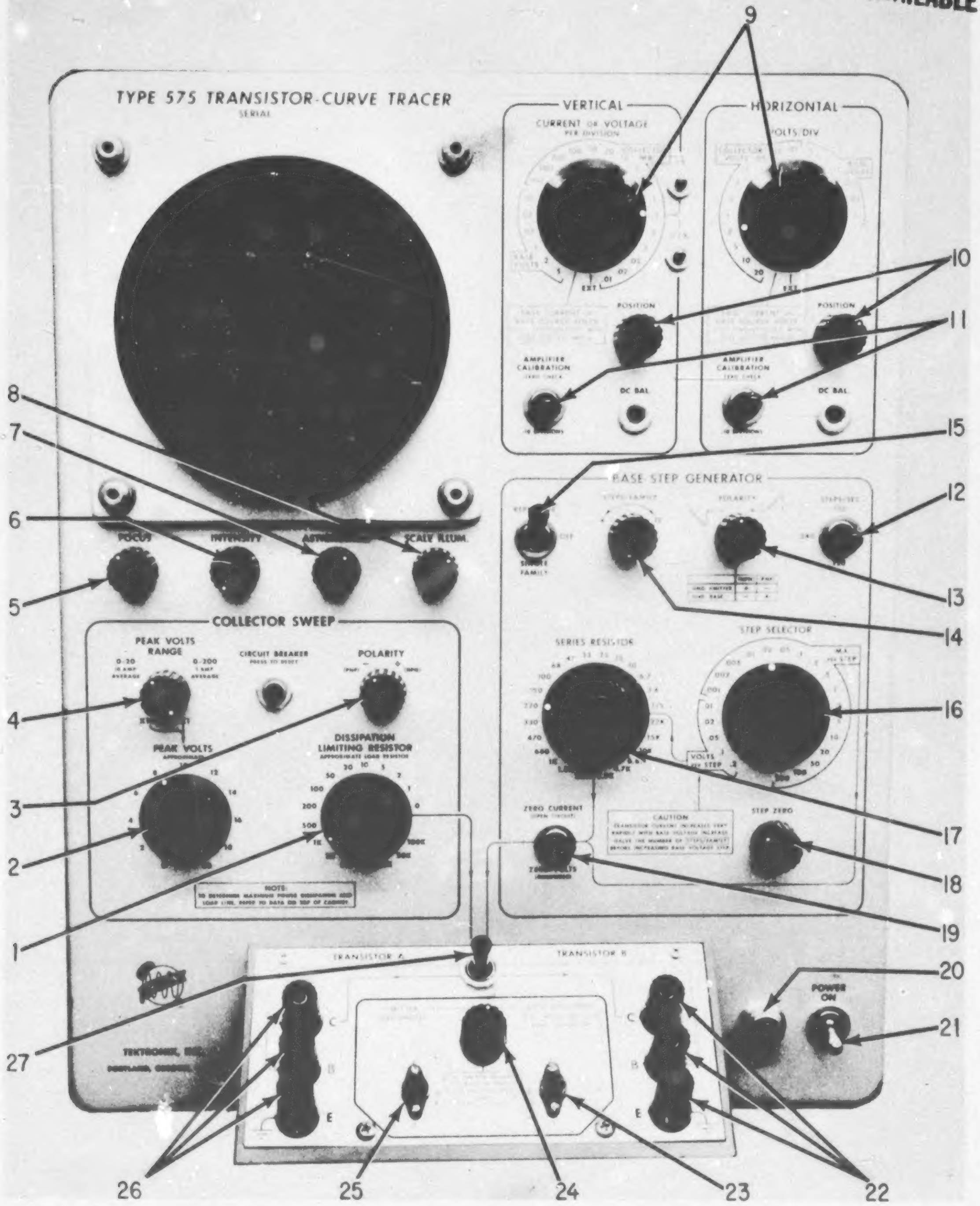
TYPE 575 TRANSISTOR-CURVE TRACER
VERTICAL
CURRENT OR VOLTAGE PER DIVISION
HORIZONTAL
VOLTS/DIV
POSITION
AMPLIFIER CALIBRATION
DC BAL
FOCUS
INTENSITY
ASTIGMATISM
SCALE ILLUM.
COLLECTOR SWEEP
PEAK VOLTS RANGE
CIRCUIT BREAKER
POLARITY
PEAK VOLTS
DISSIPATION LIMITING RESISTOR
BASE STEP GENERATOR
STEPS/FAMILY
POLARITY
SERIES RESISTOR
STEP SELECTOR
ZERO CURRENT
CAUTION
STEP ZERO
TRANSISTOR A
TRANSISTOR B
POWER ON
TEKTRONIX, INC.
PORTLAND, OREGON
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AT. 114

Figure 5-36.—Transistor curve tracer (Tektronix 575).

TRANSISTOR CURVE TRACER (TEKTRONIX 575)

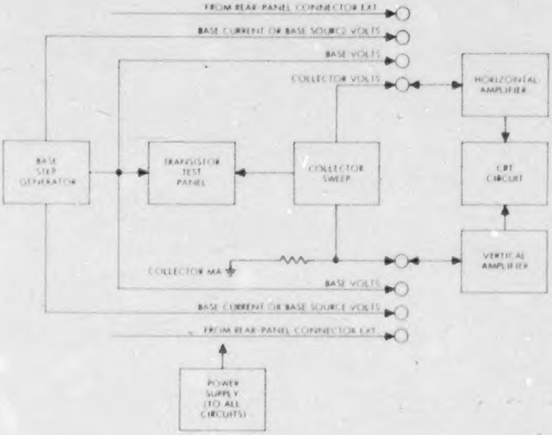
The Transistor Curve Tracer 575 is employed to plot or trace characteristic curves of transistors and other semiconductor devices. There are two different methods to plot the characteristic curves of a transistor. One is to apply d-c voltages and take measurements point-by-point. The other method is to use changing voltages and display the curve on an oscilloscope.

The 575 displays the curves by the use of the oscilloscope. There are several advantages in the use of the second method. To begin with, it is faster and more accurate than the point-by-point method. The point-by-point method may allow small irregularities in the characteristics to go undetected. Since heat is a major factor in transistor operation, errors caused by heat are reduced because the periods of applied power are shorter. Another definite advantage is that permanent records of the curves traced out on the oscilloscope may be easily produced at a reasonable cost by the use of photographic equipment.

This equipment is also provided with a self-calibration test. The operator can quickly reassure himself of the accuracy of the test set by the use of this built-in calibration check in case a displayed curve deviates from the published nominal characteristic curve. The following paragraphs describe briefly how the 575 works and outlines a method for determining dial settings for transistors found in the fleet.

An illustration of the front panel of the equipment is shown in figure 5-36. As can be seen the controls are grouped into five blocks, with a test connector panel at the base of the test set. In addition to the block arrangement the panel is also color coded to simplify the operation. The collector currents and voltages are referenced by the sections of the panel etched in red; the sections etched in blue refer to the base currents and voltages. An exception to this color code is when a common base transistor configuration is being tested, at that time the blue is in reference to the emitter.

In the description of the five functional divisions that follows, refer to figure 5-36 for the item numbers listed; a functional block diagram is also given in figure 5-37.


FROM REAR-PANEL CONNECTOR EXT
BASE CURRENT OR BASE SOURCE VOLTS
BASE VOLTS
COLLECTOR VOLTS
HORIZONTAL AMPLIFIER
BASE STEP GENERATOR
TRANSISTOR TEST PANEL
COLLECTOR SWEEP
CRT CIRCUIT
COLLECTOR MA
VERTICAL AMPLIFIER
BASE VOLTS
BASE CURRENT OR BASE SOURCE VOLTS
FROM REAR-PANEL CONNECTOR EXT
POWER SUPPLY (TO ALL CIRCUITS)

AT. 115

Figure 5-37.—Transistor curve tracer block diagram.

The collector sweep circuit supplies the transistor under test with a collector voltage which is the output of a full-wave rectifier without any filtering. The 60-Hz line voltage is supplied to the full-wave rectifier and the output of the rectifier is 120-Hz pulses. The output waveform varies from zero volts to some peak value which can be controlled from the front panel (items 2 and 4). The peak voltage can be varied in two ranges, from 0 to 20 volts and from 0 to 200 volts. The polarity of the sweep voltage can be reversed in order to check both PNP- and NPN-type transistors (item 3). A variable amount of resistance can be placed between the collector sweep supply and the transistor under test in order to limit the maximum amount of collector dissipation (item 1).

Base Step Generator

The step generator develops currents and voltages which change value in stairstep fashion in synchronization with the collector sweep voltage (items 12, 16, 17, and 18). The output of the generator can be reversed in polarity and can be connected to either the base or the emitter of the transistor under test (item 13). The number of steps can be varied from 4 to 12 according to the type of display desired (item 14).

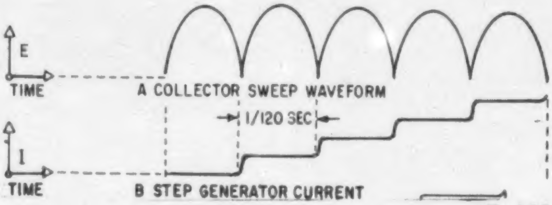
Display Function

The display function includes the three major functional blocks remaining; the vertical and horizontal amplifiers, and the cathode-ray tube. (A description of the operation of a cathode-ray tube is given in Basic Electronics; an oscilloscope is also discussed later in this chapter.)

The horizontal and vertical amplifiers of the cathode-ray tube display can be driven by several different inputs, depending upon what characteristics are of interest (item 9). The horizontal amplifier can select any of four inputs and display one of them on the horizontal axis. The four inputs are base volts, collector volts, base current or base-source volts, and external. In the base volts position, the horizontal amplifier is connected to the base of the transistor under test. In the collector volt position, the horizontal amplifier is connected to the collector of the transistor under test. Both of these inputs have several positions so that the scaling factor can be changed. The base-current or base-source volts position connects the output of the base step generator into the horizontal amplifier. The external position connects the horizontal amplifier to two coax connectors on the rear of the instrument.

The vertical amplifier can also select from four different inputs: collector MA, base volts, base current or base-source volts, and external. Base volts, base current or base-source volts, and external positions are the same as described for the horizontal amplifier, but in the collector MA position, the vertical axis will give a plot of collector current.

INTERPRETING THE DISPLAY.–As the collector voltage changes from zero to some peak value and back to zero again, the step generator output remains at some specific level and then changes to some new level for the next collector voltage cycle. The collector voltage is swept at a rate of 120 Hz, and the step generator changes steps or level after every cycle (in the 240 steps per second, the step generator changes at both the zero point of the collector sweep and at the maximum point). Figure 5-38 is a plot of collector sweep voltage and base step generator current. It should be noted that the collector sweep makes a complete excursion, while the base is at some steady value. As the next collector sweep starts, the base current is changed to the next value of current selected by the dials on the front of the instrument, and again the base current will remain steady while the collector voltage is varied.

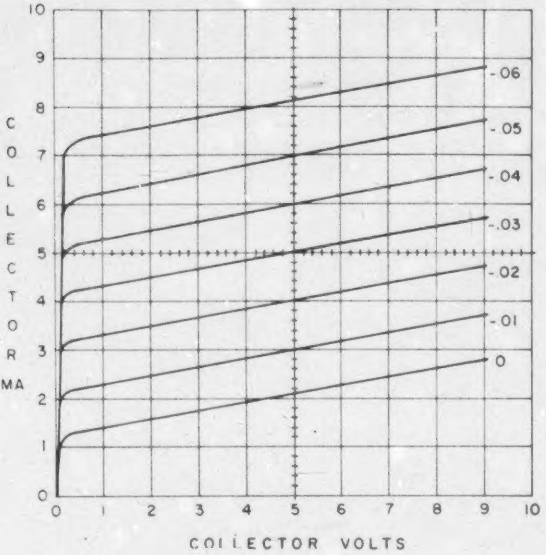


AT. 116

Figure 5-38.—Waveforms of collector sweep versus step generator current.

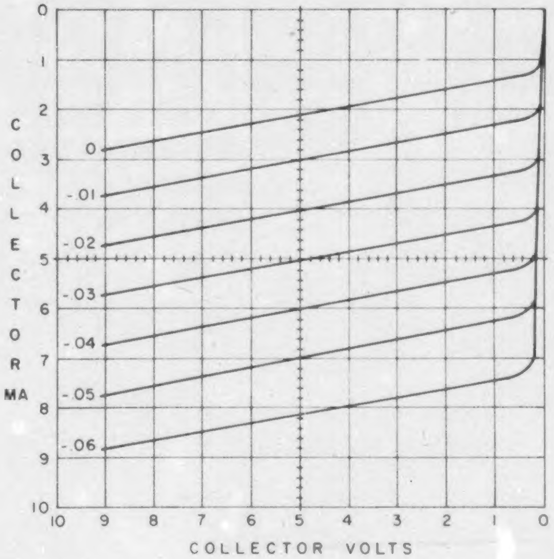
As previously mentioned, the waveforms of figure 5-38 can be reversed by switches on the front panel in order to check either PNP or NPN.

Figure 5-39 is a plot of collector voltage and collector current for given values of base current for an NPN transistor. For this type of transistor, it is a convention to have the lower left-hand corner represent zero collector voltage and current. In this graph, it was arbitrarily decided that each division to the right of the lower left-hand corner of the horizontal axis would represent a collector voltage change of one more volt positive. This would indicate a collector voltage swing of zero to 10 volts positive. The vertical axis is a plot of collector current varying from zero milliamperes in the lower left-hand corner to 10 milliamperes at the top of the graph in 1 milliampere steps. The different lines on the graph represent different values of base current; in this case, each line represents a change of 0.01 milliampere. If this graph had been for a PNP rather than for an NPN, the upper right-hand corner would have represented zero collector voltage and zero collector current. The divisions to the left would have represented negative collector voltage and the di-



AT. 117

Figure 5-39.—Typical NPN collector curves.



AT. 118

Figure 5-40.—Typical PNP collector curves.

visions downward from the top would have indicated the amount of negative current. This would have made the family of curves to appear as shown in figure 5-40.

These curves are known as the static collector characteristics for a common emitter configuration or output characteristics curve. Curves can be developed for common base and common collector also, but normally the information is available for the common emitter mode. Using this configuration, it is easier to check the transistor. To thoroughly describe how a transistor is going to work in a circuit, it is necessary to know the input characteristic curve as well as the output curve. The input characteristic curve is developed by plotting base current on the horizontal axis, base to emitter voltage (V_{BE}) on the vertical axis at different values of collector to emitter voltage (V_{CE}). Although it is necessary for the design engineer to know the input characteristic curve when designing a circuit, the output characteristic curve will normally give the maintenance technician enough information to allow him to evaluate a transistor.

Measuring Beta (h_{fe})

One means of measuring the quality of a transistor is the Beta (β) or current gain in the common emitter configuration. Mathematically, Beta is represented by the formula

$$\beta = \frac{\Delta ic}{\Delta ib}$$

where V_{CE} is constant. Beta is also called the forward current transfer ratio and represented by the symbol h_{fe}, which is derived from the hybrid equivalent circuit of a transistor. To determine the Beta from the output characteristics, measure the change in collector current between two values of base current at some constant collector voltage; for instance, in figure 5-39, to determine the Beta at a collector voltage of 5 volts, measure the change in collector current between the base current curves of 0.02 ma and 0.03 ma. In this example, the change in collector current measures 1 ma, so the Beta is equal to the change in collector current divided by the change in base current or

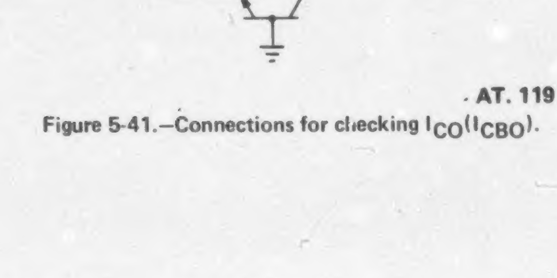
$$\frac{1 \times 10^{-3}}{0.01 \times 10^{-3}} = 100$$

Measuring I_{CO}

Another characteristic of a transistor is the I_{CO}, also called I_{CBO}. This is the collector current when the collector is biased in the reverse direction (high resistance, normal connection) with respect to the base, and the emitter is open-circuited. The I_{CO} of a transistor is highly temperature-dependent and the measurement made with the curve tracer will be at the ambient temperature only; but it is still significant. The method used to measure the I_{CO} is shown schematically in figure 5-41. Notice that the emitter is not connected.

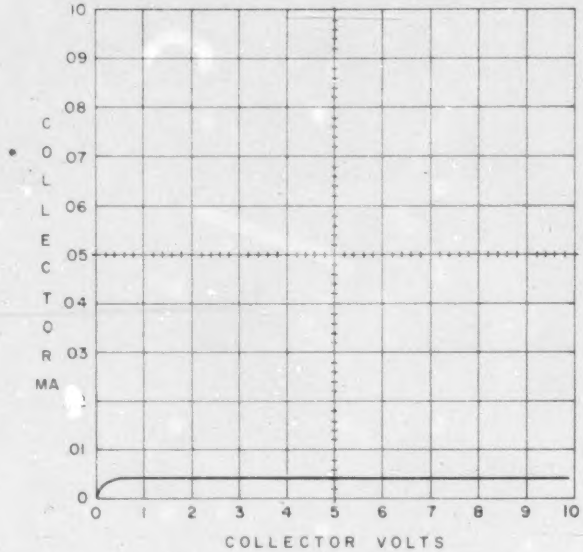
The display of the curve tracer when measuring I_{CO} is shown in figure 5-42. The vertical axis indicates collector current, just as it did when Beta was being measured; but now the vertical amplifier is adjusted to afford maximum gain so that the small amount of current causes a noticeable deflection. The horizontal axis is still calibrated to show collector voltage.

The technician must know the Beta and I_{CO} of a transistor in order to tell whether or not the one he is testing is good. Since no manual describing the characteristics of different transistors is provided with the curve tracer, it is necessary to obtain this information from other sources. NavAir 16-1-530 Replacement Guide, Semiconductor Device (Transistors and Semiconductor Diodes), dated May 1963, is an excellent source. For those transistors not listed in this publication, a specification sheet can be obtained from the manufacturer.



AT. 119

Figure 5-41.—Connections for checking $I_{CO}(I_{CBO})$.



AT. 120

Figure 5-42.—Typical display of $I_{CO}(I_{CBO})$.

Section 1A of NA 16-1-530 is a list of transistor replacements. Section 1A also gives the technical section in which a specific transistor is listed. These are Sections 2 through 10. To use this manual, look up the transistor in the technical section which applies; descriptions at the top of each page tell whether the transistor is germanium or silicon, PNP or NPN, low or high power. The important columns in the technical section needed to obtain information on testing are MAXIMUM COLLECTOR DISSIPATION, ABSOLUTE MAX RATINGS, MAX I_{CBO} at MAX V_{CB}, Typical "h" Parameters at 25° C.

Under the column labeled Typical "h" Parameters, there is listed a typical h_{fe} or a minimum and maximum value of h_{fe} depending on which technical section the transistor is listed in. In the same column is listed the collector voltage and collector current at which this h_{fe} is to be obtained.

The collector voltage (V_{CE}) and collector current (I_C) provide the starting points from which to determine the curve tracer settings; for instance, if the V_{CE} is 5 volts, the horizontal amplifier would be set to COLLECT or VOLTS, 1 volt per division. This would place the 5-volt position in the middle of the display, and if the I_C is 1-ma, the vertical amplifier would be set to COLLECT or MA, 0.2 MA per division. This would place the 1-ma position in the middle of the display. The collector sweep can be determined from these settings, since the horizontal amplifier is set to 1 volt per division. The collector voltage varies a total of 10 volts, so the PEAK VOLTS RANGE is in the 0 - 20 position and the PEAK VOLTS control is set at 10. To determine the setting for the DISSIPATION LIMITING RESISTOR, obtain the maximum collector dissipation from the column in the technical section labeled MAX COLL DISS. This, in conjunction with the setting of the PEAK VOLTS control, can be plotted on the chart on top of the curve tracer to obtain the correct setting of the limiting resistor.

The step generator is set up in the following manner. The switch labeled REPETITIVE-OFF-SINGLE FAMILY is set to REPETITIVE, and the control labeled STEPS/FAMILY is set counterclockwise. This gives four steps per family, which is usually sufficient; but if more are desired, set STEPS/FAMILY to any value. The switch labeled POLARITY has a chart under it showing the correct position for NPN and PNP. Use the portion of the chart pertaining to grounded emitter-type circuits. The switch labeled STEPS/SEC can be in either of the two 120 positions or in the 240. The only difference in the two 120 positions is that at one of them, the step generator changes level when the collector is at zero volts; and at the other position, the step generator changes level when the collector is at the maximum voltage. In the 240 position, the step generator changes level at both the zero collector voltage and at the maximum point. The step selector can be set by starting at the smallest change per step (0.001 ma) and increasing the size of the step until the display has the necessary separation between the values of base current to determine Beta. In the alternate procedure, the Beta listed in the technical section can be divided into the amount of collector current and the result used as the setting of the step selector. If there is not enough separation between the lines representing the base current to accurately determine the Beta, increase the amount of each base step until a good display is obtained.

To check the I_{CO} of the transistor, disconnect the emitter and change the current per division setting on the vertical amplifier to the most sensitive position (0.01 ma). Set the step zero very accurately, as described in NA 16-45-107, which is the Service Instruction Manual and Operating Instruction Manual for the curve tracer. After setting the step zero, note the difference between the step zero and the present position of the trace; this is an indication of the I_{CO}. The I_{CO} of the transistor is listed in the technical section, in the column MAX I_{CBO} at MAX V_{CB}, which describes the I_{CO} at BV_{CBO} —the breakdown voltage, collector-to-base with emitter open.

By measuring Beta (h_{fe}) and I_{CO} (I_{CBO}), a fair picture of the condition of a transistor is presented. There is one thing that should be mentioned in connection with the curve tracer, however; matching of transistors. Some Navy equipments have matched pairs of transistors, but unless the specifications are checked, it cannot be automatically assumed that Betas of the transistors are matched. Sometimes the Betas are matched, sometimes they are not; many times several characteristics are matched.

SIGNAL GENERATORS

The principal function of a signal generator is the production of signals having the specific characteristics required for the test or measurement in question. It is very important that the amplitude of the generated signal be correct. In many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the generator, the test equipment output signal is coupled into the circuit being tested. Its progress through the equipment may then be traced by the use of high impedance indicating devices such as vacuum tube voltmeters or oscilloscopes. In many signal generators, attenuators are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are desirable since the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of sinusoidal signal generators. It is possible to classify them roughly by frequency into audio generators, generators of both the audio and video ranges, radiofrequency generators, frequency-modulated RF generators, and special types which combine all of these frequency ranges.

In addition, signals other than sinusoidal are also generated for testing of equipment. The signal generators producing nonsinusoidal outputs are usually classified according to the type of signals they produce. Some signal generators produce several types of signal waveforms.

In almost all currently used types of signal generators, electron tube oscillators are used to produce the initial signal. In order to achieve accurate results in the use of the signal source, it is necessary to allow the oscillator circuits to reach a condition of stable operation before applying the output. This condition is reached when the tubes and circuit elements attain the temperature at which the instrument was calibrated.

A preliminary warmup should always be given the generator when accurate and stable signals are desired. The minimum warmup time for the generator is contained in the Service Instruction Manual for each model. In the sections immediately following, there is a discussion of several types of generators.

In testing the receiver section of a transceiver, the output of the signal generator is usually connected to the antenna terminal of the transceiver. If the transceiver is then keyed, damage to the signal generator results. This damage usually includes burning out of the resistive elements of the signal generator output circuits; these elements are rated only for the comparatively low power of the signal generator. In this type testing configuration, it is essential that some form of protection be given the test equipment.

One form of protection which can be provided is a fuse in series between the signal generator output terminal and the transceiver antenna terminal. The value of the fuse is dictated by the output limitations of the signal generator—usually about 1/16 ampere is recommended.

SINE WAVE GENERATORS

Sine wave generators will be discussed under the heading of three classes. These classes are audio, video, and radiofrequency. The sine wave generator is used to produce simulated conditions for the alinement and testing of equipments.

Audio and Video

Audio signal generators produce stable audiofrequency signals used for testing audio equipment. Video signal generators produce signals which include the audio range and extend considerably further into the RF range. These generators are used in testing video amplifiers and other wideband circuits. In both audio and video generators, the major components include a power supply, an oscillator (or oscillators), one or more amplifiers, and an output control. Voltage regulation circuits are necessary to insure stability of the oscillator in generators which derive power from 115-volt, a-c sources. In portable generators, battery power supplies are usually used, and these require no voltage regulation.

In the audio and video generators of the beat-frequency type, the output frequency is produced by mixing the signals of two radiofrequency oscillators, one of which is fixed in frequency and the other variable. The difference in frequency of the two is equal to the desired audio or video frequency. For example, if the fixed and variable oscillators both produce a frequency of 400 kHz, the resultant output frequency is zero. If the variable oscillator is changed to 401 kHz, the resultant is then 1 kHz. By action of this type, any desired frequency in the range of the circuits may be produced in the output.

Audio signal generators often include RC oscillators in which the audio frequency is directly produced. In these, a resistance-capacitance circuit is the frequency determining part of the oscillator. The frequency varies when either the resistance or the capacitance is changed in value. In commercial generators, however, the capacitance alone is often chosen as the variable element. The change in frequency which can be produced by this method is limited, and it is usually necessary to cover the entire range of the generator in steps. This is accomplished by providing several RC circuits, each corresponding to a portion of the entire range of frequency values. The RC circuits in the oscillator are switched to cover the desired portion of the audio range.

The amplifier section of the block diagram of figure 5-43 usually consists of a voltage amplifier and one or two power amplifiers. These are coupled by means of RC networks, and the output of the final power amplifier is often coupled to the attenuator, or output control, by means of an output transformer.

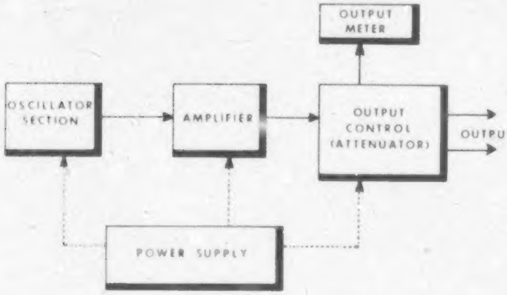
The output control section provides a means of matching the output signal to the input of the equipment under test and regulating the amplitude of the signal. The settings of the output control knob provide output voltage values which are either inscribed directly on the knob or which can be interpreted by reference to the instruction manual provided with the generator.

Radiofrequency

A typical radiofrequency signal generator contains, in addition to the necessary power supply, three main sections—an oscillator circuit, a modulator, and an output control circuit. The internal modulator modulates the radiofrequency signal of the oscillator. In addition, most RF generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to prevent the entrance of signals from the oscillator into the circuit under test by means other than through the output circuit of the generator.

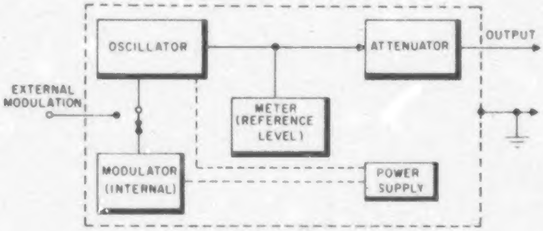
A block diagram of a typical RF signal generator is shown in figure 5-44. The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of frequencies for which the generator is designed. In low frequency signal generators, the resonating circuit consists of one of a group of coils combined with a variable capacitor. One of the coils is selected with a range selector which attaches it to the capacitor to provide an LC circuit which has the correct range of resonant frequencies.

In signal generators designed for the higher frequencies, the resonating circuits are usually in



AT. 121

Figure 5-43.—Block diagram of typical audio or video signal generator.



AT. 122

Figure 5-44.—Block diagram of a radiofrequency signal generator.

the form of butterfly tuning circuits and resonant cavities. Reflex klystron oscillators are often used in generators of frequencies above 1000 MHz.

In any signal generator, it is required that the oscillators have good stability both in frequency and amplitude over a wide range of output frequencies.

The function of the modulating circuit is the production of an audio (or video) voltage which can be superimposed on the RF signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator (internal modulation), or it may be derived from an external source. In some signal generators, either of these methods of modulation may be employed. In addition, a means of disabling the modulator section is used whereby the pure unmodulated signal from the oscillator can be used when it is desired.

The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provision is made for pulse modulation in which the RF signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator by indicating arbitrary values of output read in tenths through the value of one.

The attenuator selects the amount of this output. The attenuator, a group of resistors forming a voltage-dropping circuit, is controlled by a knob which is often calibrated in microvolts. When the control element is adjusted so that the output meter reads unity (1.0), the reading on the attenuator knob gives the exact value (no multiplication factor) of the output in microvolts.

If output voltage is desired at a lower value, the control is varied until the meter indicates some decimal value less than one; this decimal is multiplied by the attenuator reading to give the output in microvolts.

SG-85/URM-25D.–RF Signal Generator Set AN/URM-25D is typical of most RF signal generators in common usage. It consists of Signal Generator SG-85/URM-25D, its case, and an assortment of accessory items.

It is intended primarily for bench testing of electronic equipment, covering the frequency range from 10 kHz to 50,000 kHz. This frequency coverage is accomplished in eight bands, and the RF output can be either modulated or unmodulated. The frequency generated can be read from a main frequency scale within an accuracy of ±0.5 percent; and by proper use of a 1-MHz internal crystal calibrator, the accuracy can be increased to 0.05 percent above 1 MHz.

This test set also generates an audio signal of 400 or 1000 hertz, which is used to modulate the RF carrier. The audio signals are also separately available at the front panel.

FM SIGNAL GENERATORS.–Frequency-modulated RF signal generators are widely used for testing frequency-modulated receivers and for visual alinement (using an oscilloscope) of AM receivers. A frequency-modulated signal is an alternating voltage in which the frequency varies above and below a given center frequency value. The overall frequency change is called the frequency swing.

There are several methods by which the frequency of the oscillator in the signal generator may be frequency modulated. In one type of FM generator, use is made of a vibrating plate which forms one of the elements of the tuning capacitor of the oscillator to be modulated. The plate is driven by a device similar to a magnetic loudspeaker. The audio modulating voltage is applied to the driving coil which moves in the field of a permanent magnet and vibrates the plate of the capacitor at the applied audiofrequency. Movement of the plate causes variation of the capacitance in the oscillator tuning circuit with the result that the frequency of the oscillator is periodically raised or lowered.

Another method of producing frequency modulation is based on the action of a reactance tube which is connected in parallel with the tuning circuit of the oscillator to be modulated. A reactance tube is an electron tube in which the plate current is made either to lead or to lag the plate voltage variations by 90°. Because of this phase difference, the plate circuit of the tube is electrically equivalent either to a capacitor or to an inductance. The modulating voltage is impressed on the grid of the reactance tube, causing the capacitive (or inductive) reactance of the plate circuit of the tube to vary. Since the reactance tube plate circuit as a part of the oscillator tuning circuit, variation in the reactance value causes the generated frequency to vary in step with the modulating voltage.

In signal generators of microwave frequencies, frequency modulation is easily accomplished in the oscillator by applying the modulating voltage to the repeller plate of the reflex klystron tube which is usually employed in these generators.

SWEEP GENERATOR AN/URM-75

Sweep Generator AN/URM-75 is a versatile precision test instrument used for alining and checking radio receivers in the frequency range of 5 to 220 MHz. Its major component is the SG-93/URM-75 sweep generator, which supplies signals for the following functions:

1. Observing frequency response, relative gain, and bandpass characteristics of RF, IF, and video stages.
2. Alining RF and IF circuits.
3. Checking and adjusting discriminators.
4. Determining relative receiver sensitivity.

Basically, the unit consists of an FM sweep oscillator, a marker oscillator, a crystal oscillator, an audio oscillator, a frequency converter, a blanking circuit, and two output jacks.

The FM sweep oscillator is tunable over a frequency range of 50 to 220 MHz. In conjunction with the sweep converter stage, the oscillator produces a sweep signal which is variable from 5 to 220 MHz. This extended range is covered in two bands.

On band B, the sweep converter is disabled and the sweep oscillator operates alone to cover the range of 50 to 220 MHz. On band A, the sweep oscillator signal is beat against a 116.5 MHz signal from a fixed frequency oscillator in the converter stage. This beat produces a signal which is variable from 5 to 50 MHz. The sweep output is available at the MIXED OUTPUT jack. The signal may be used alone or in conjunction with a marker signal.

The marker oscillator operates over a frequency range of 4 to 220 MHz, covered in six bands. The marker signal, either modulated or unmodulated, is then supplied to both the MKR OUT jack and the MIXED OUTPUT jack. By means of this signal, the exact frequency may be determined for any point along a frequency response curve produced by the sweep signal.

The crystal oscillator is normally operated at a fundamental frequency of 10 MHz. By insertion of the appropriate crystal, however, oscillation may occur between 4 and 15 MHz. The crystal oscillator output, either modulated or unmodulated, is supplied to both output jacks. This signal provides a means of correctly calibrating the marker oscillator, or of calibrating external signals.

The audio oscillator generates a signal of 600 Hz which may be used to modulate the marker output and/or the crystal oscillator output, if desired. It is not available as a separate output.

The generator incorporates an optional blanking circuit which produces a 60-Hz sine wave. The positive half of the sine wave is eliminated, and the negative half is applied to the grid of the FM sweep oscillator. This input cuts off the FM sweep during the period of the half cycle. Thus, when the operator activates the blanking circuit, the FM sweep oscillator produces pulses of energy occurring at a 60-Hz rate.

PULSE GENERATOR AN/URM-44A

The generation of pulse signals involves many fundamental electronic circuits and some special purpose tubes. Some of the circuits involved are multivibrators, limiters, clampers, discriminators, oscillators, and sawtooth generators. One of the special purpose vacuum tubes is the reflex klystron, which is used as an oscillator.

The TS-622A/U is a typical pulse generator. It is the main component of Radio Test Set AN/URM 44A.

The TS-622 is a signal generator of low power output and is used in the maintenance of radio and radar equipment operating in the frequency range between 7,000 and 10,750 MHz. It produces continuous-wave, pulse-modulated, and frequency-modulated signals. The output frequency and power level of the test set are indicated on separate direct reading dials located on the front panel.

In the pulse-modulated mode of operation, pulse widths of 0.5 to 10 microseconds may be obtained, and the pulse repetition may be adjusted from 40 to 4,000 pulses per second. Pulse modulation is obtained from a multivibrator which produces square waves of the above mentioned pulse widths and frequency.

In the frequency-modulated mode of operation, a sawtooth generator supplies a sawtooth of voltage to the reflex klystron to cause the signal to be frequency modulated.

In the CW mode of operation, the klystron is permitted to free-run at the frequency selected.

This test set includes an internal synchronizing generator (the multivibrator), and has provision for applying an external synchronizing signal of either positive or negative polarity. It also has provision for an external modulating signal to be applied.

The front panel provides the following three outputs:

1. The RF output, which is the output from the klystron oscillator.
2. An undelayed sync (undelayed synchronizing voltage).
3. A delayed sync. The syncs are either the output from the internal sync generator or an input from the external sync source.

The Service Instruction Manual, NA 16-30URM44-6 contains a breakdown of all circuits of the test set and detailed theory of operation of each. Also included in the manual is a master block diagram to simplify the explanations.

PULSE GENERATOR AN/UPM-[illegible]

This equipment is basically a pulse generator and a synchroscope, combined into a single unit. It is used to generate, display, and measure pulse test signals. It consists of Pulse Generator SG-30/UP, its transit case, and the associated cables, adapters, accessories, and technical manuals. Operation of the equipment involves the use of high potentials which are dangerous to life. Safety precautions must be observed.

The Pulse Generator SG-30/UP has been designed to furnish rectangular voltages of adjustable duration, amplitude, and repetition frequency. These pulses are delayed so that they follow trigger pulses by an adjustable time interval. The equipment may be triggered by an external signal, or it may be triggered by an internally generated audio-frequency signal. Internally generated pulse, trigger, and audio signals are made available at output terminals on the front panel.

The synchroscope located in the same unit is capable of accurately determining the waveshape, amplitude, duration, and time relationship of the output pulses. The equipment is suitable for use in maintaining airborne or ground electronic equipment. The design and construction of the unit makes it adaptable for work performed in laboratories or in maintenance shops located aboard ship or on land.

MULTIPLE-SIGNAL GENERATORS

Signal Generator SG-321A/U provides multiple output signals which are essentially transient-free over a frequency range of 0.008 to 1200 Hz in five bands. The versatility of the equipment and the quality of its generated signals make the SG-321 useful for any general purpose testing application within its frequency range. It is especially useful in the testing of servosystems and mechanically operating systems, and in the electrical simulation of mechanical operations.

The outputs available from this equipment include square and triangular waveforms, both of which are inherent in the basic oscillating system. In addition, a sine wave is developed by modifying (synthesizing) the triangular waveform. A sync output pulse is also made available for external use.

The basic oscillating system uses a type of relaxation oscillator that is especially well adapted to the generation of very low frequencies. Both the triangular and the square wave of voltage as a function of time are inherent in the system.

Any type of AVC system causes a delay in the stabilization of an output response following a change in operating frequency. The oscillating system of the SG-321A/U is a constant amplitude device which requires no AVC system. The output amplitude and distortion of signals is therefore almost completely independent of frequency.

The signal generator is rated to deliver at least 30 volts peak to peak into a 4000-ohm load. The sync output is a negative pulse of 10 volts amplitude and a duration of less than 5 microseconds. The sync pulse occurs at the crest of the sine wave, and at corresponding points on the other waveshapes.

PULSE-MODULATED RF SIGNAL GENERATOR MODEL 628A

A pulse-modulated (FM) signal generator is similar to the conventional RF signal generator with the exception that its output consists of RF energy in the form of pulses which occur at an audio rate. Controls are provided to vary the pulse width (duration of each pulse) and the repetition rate (number of pulses per second). A common application of a pulse-modulated generator is found in the checking of receiver performance of many radar systems which employ a pulse type emission.

Pulse-modulated RF signals are produced by generating a constant RF carrier by means of a conventional oscillator circuit and feeding this energy to the grid of a mixer stage which has at the same time impressed on its suppressor grid a square wave generated in a separate circuit. The positive half-cycles of the square wave allow the mixer tube to conduct, and the negative half-cycles cut the tube off. During the conducting intervals, the plate current is varied by the RF signal on the control grid. Therefore, pulses of RF current, corresponding to the positive half-cycles of the square wave, appear in the mixer plate circuit. The pulses are generally fed to one or more amplifier stages. Pulse time and repetition rate are varied by controls in the square wave circuit.

The Model 628A SHF signal generator (fig. 5-45) is a general purpose broadband signal generator which produces RF output voltages from 15 GHz to 21 GHz. A single control determines the output frequency which is directly read on a dial calibrated to an accuracy of 1 percent or better.

The 628A signal generator is provided with versatile modulation characteristics. The output can be frequency modulated, square wave modulated, or pulse modulated by internally or externally generated signals. It also provides synchronizing pulses for external equipment being used.

The 628A signal generator, in addition to producing an accurate and controllable radiofrequency test signal, can be used for the following:

1. Testing pulse systems.
2. Measuring sensitivity and selectivity of amplifiers, receivers, and other tuned systems.
3. Measuring signal-to-noise ratio of RF signals.
4. Making slotted line measurements.
5. Investigation of microwave impedances and other transmission line characteristics.
6. Measuring frequency response of microwave systems.
7. Determining resonant frequency and Q of waveguide cavities.

Operating Procedure

The operation of the 628A signal generator consists of adjusting two major sections—the RF section and the modulator section. The RF section is adjusted first since this adjustment establishes the output power reference level for the output attenuators.

Figure 5-46 displays the front panel controls and connectors used in the operation of the 628A signal generator. A brief description of the function or operation of the front panel controls and connectors follows:

1. Supplies line power to the instrument.
2. OUTPUT ATTEN control—determines the RF output level from +10 dbm to −90 dbm (10 mw to 1 $\mu\mu$w).
3. MOD SELECTOR switch—used to select the desired type of modulation to be applied to the RF output signal.
4. EXT MOD/SWEEP OUT—used as an input for external modulation signals when MOD SELECTOR is set to EXT FM, EXT−, or EXT+; used as an output for a sweep signal which occurs only when MOD SELECTOR is set to INT FM.
5. SYNC IN connector—input for sync pulses. These pulses are used only when MOD SELECTOR is set to INT and SYNC SELECTOR to EXT−, EXT+, or ~.
6. SYNC OUT connector—output for sync pulses in either square wave or pulse operation.
7. DELAYED SYNC OUT connector—output for delayed sync pulses in either square wave or pulse operation. These pulses are controlled by PULSE DELAY.

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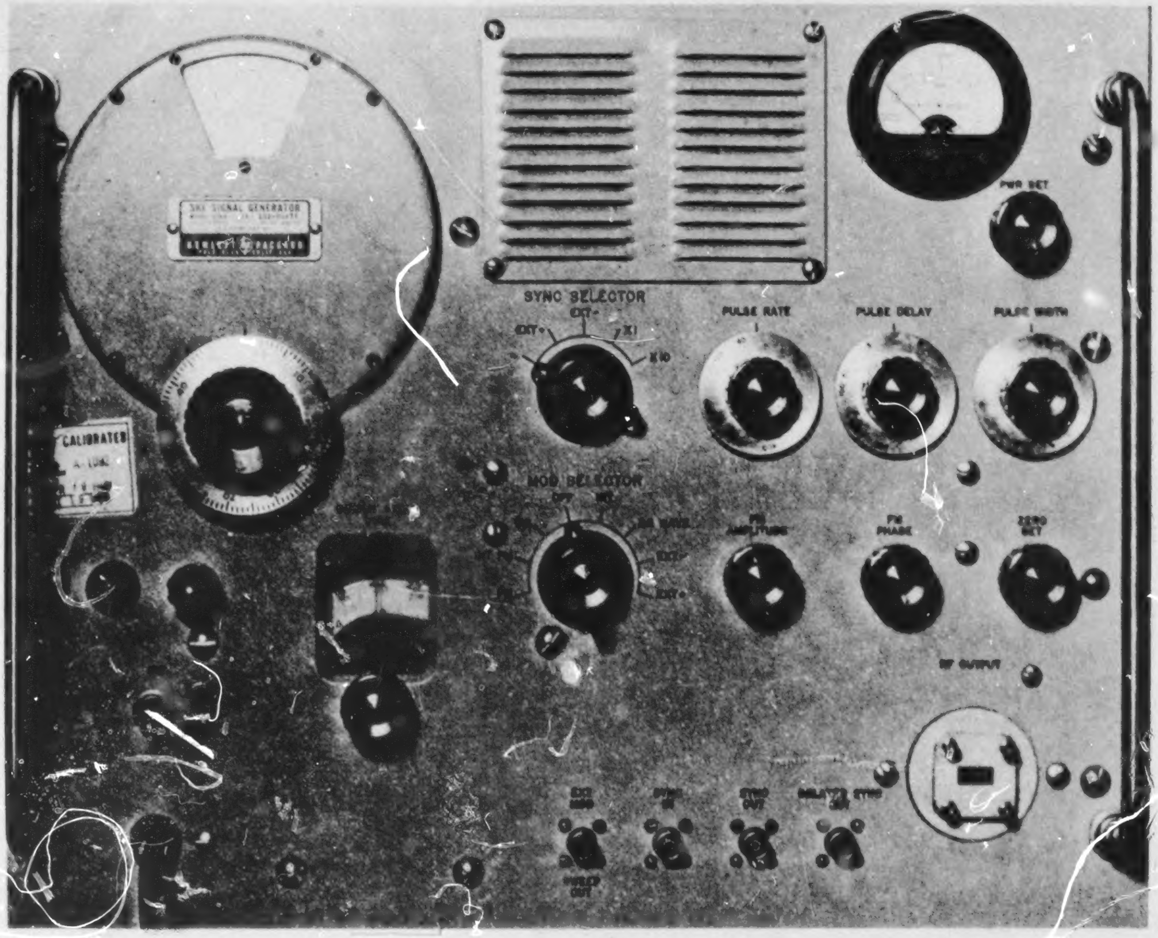

SHF SIGNAL GENERATOR
HEWLETT PACKARD
CALIBRATED
PWR SET
SYNC SELECTOR
EXT+
EXT-
X1
X10
PULSE RATE
PULSE DELAY
PULSE WIDTH
MOD SELECTOR
OFF
INT
EXT+
EXT-
FM AMPLITUDE
FM PHASE
ZERO SET
RF OUTPUT
SYNC IN
SYNC OUT
SWEEP OUT

AQ. 602

Figure 5-45.—Model 628A SHF signal generator.

8. RF OUTPUT—N band type WR-51 waveguide, cover type flange.

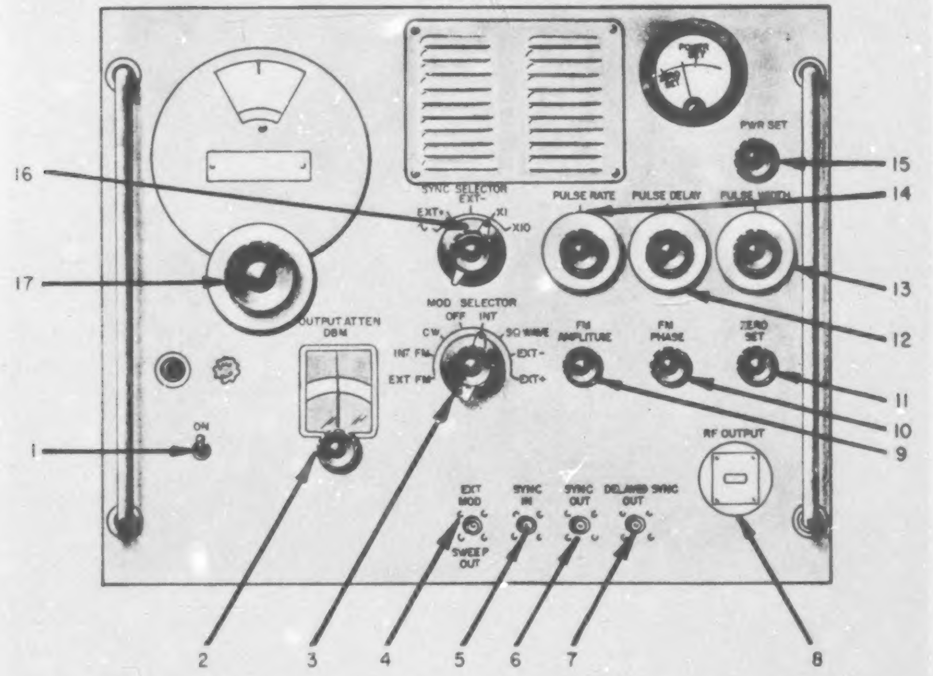
9. FM AMPLITUDE control—determines the frequency deviation of the output signal when internal or external frequency modulation is employed.

10. FM PHASE control—determines the phase of frequency modulation from approximately +90° to −90° with respect to the SWEEP OUT signal only when internal frequency modulation is employed.

11. ZERO SET control—used to zero-set the power-monitor meter.

12. PULSE DELAY control—adjusts the time delay between the leading edge of the SYNC OUT pulse and the RF output pulse from 3 to 300 microseconds when the MOD SELECTOR is set to INT.

13. PULSE WIDTH control—adjusts the width of the RF output pulse from 0.5 to 10 microseconds when the MOD SELECTOR is set to INT.


PWR SET
SYNC SELECTOR
EXT-
EXT+
X1
X10
PULSE RATE
PULSE DELAY
PULSE WIDTH
MOD SELECTOR
OFF
INT
CW
SQ WAVE
INT FM
EXT-
EXT FM
EXT+
OUTPUT ATTEN
DBM
FM AMPLITUDE
FM PHASE
ZERO SET
ON
RF OUTPUT
EXT MOD
SWEEP OUT
SYNC IN
SYNC OUT
DELAYED SYNC OUT
1
2
3
4
5
6
7
8
9
10
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16
17

AQ. 603

Figure 5-46.—Model 628A SHF signal generator front panel controls and connectors.

14. PULSE RATE control—adjusts the repetition rate of the RF output pulse or square wave when the MOD SELECTOR is set to INT or SQ WAVE. The X1 or X10 position of the SYNC SELECTOR selects the multiplying factor to be applied to the reading of the calibrated PULSE RATE dial.

15. PWR SET control—used to establish the correct power level fed to the output attenuators.

16. SYNC SELECTOR switch—selects the type of synchronization to be employed by the signal generator during internal pulse modulation of the RF output signal.

17. FREQUENCY CONTROL—used to set the desired RF output frequency. Frequency dial is read directly in kilomegahertz (GHz).

After turning the instrument on, allow at least 5 minutes for it to reach a stable operating temperature. If the ambient temperature is below 50°F, a longer warmup period is necessary. NOTE: The klystron tube contained in this instrument is expensive and has a shorter life than that of most conventional vacuum tubes. Filament and plate voltages remain on the klystron tube when the MOD SELECTOR switch is in the OFF position; therefore, power should be removed from the instrument when it is not in use in order to increase the useful life of the tube. Figure 5-46 indicates by number the turn-on procedure and CW operation. Turn-on procedure and CW operation is as follows:

1. Switch (1) to ON and allow at least a 5-minute warmup.

2. Set frequency dial (17) for desired frequency.

3. Set MOD SELECTOR (3) to OFF.
4. Adjust ZERO SET (11) to obtain a power-
nitor meter indication exactly on ZERO SET
lex.
5. Set MOD SELECTOR (3) to CW.
6. Adjust PWR SET (15) to obtain a meter
lication exactly on POWER SET index (red
e at center of scale).
7. Set OUTPUT ATTEN (2) for desired CW
tput level.

SIGNAL ANALYZERS

Signal analyzers, while used in many different
uations, generally aid in the accomplishment
only one function, that is to check the
ponse of an equipment under simulated con-
ions of specific operations.

ODULATION MEASUREMENT

Modulation characteristics can be determined
waveform measurement or by use of modula-
n meters (which are special applications of
ic test equipment). Modulation measure-
nts are sometimes required during tuning
ocedures to adjust transmitting equipment for
proper amount of modulation. During main-
nance tests of modulated transmitter equip-
nt, the amount of distortion of the output
nal and the modulation level or index should
determined.

The modulation level of carrier signals in
ltiplexing equipment is usually set at the
tory or in the shop during corrective main-
nance procedures. Proper adjustment of the
ut signal level and automatic signal level
ulation circuits provide the correct amount of
dulation. Defects in modulation circuits can
detected by measurements of the quality of
received signals. Corrective maintenance
alysis of multiplex equipment modulation
cuits can usually be made by signal level
asurements. Therefore, specific modulation
asurements are normally not required for a
rier equipment which operates in the audio-
quency to medium frequency RF range.

Most amplitude modulated radio transmitters
ich operate in the low frequency to high
quency range must be adjusted for correct
dulation during normal tuning procedures. If
the modulation level is low, the transmitter is not operating at its maximum efficiency; on the other hand, modulation in excess of 100 percent produces serious distortion. Since either of these conditions is undersirable, amplitude modulation should be maintained between 60 and 95 percent when possible. The modulator amplifier gain can be initially adjusted by use of an oscilloscope or a modulation meter.

The modulation level or index of AM and FM radio transmitters which operate in the VHF range is usually adjusted by the manufacturer or in the shop during corrective maintenance. Amplitude modulation of radio transmitters in this frequency range can usually be measured by the same methods employed for transmitters in the LF to HF range.

Frequency modulation measurements can be obtained by the use of an audiofrequency signal generator and a receiver with a beat-frequency oscillator. The modulation index can also be determined by a comparison method, using a frequency-modulated signal generator having a calibrated modulation control, an AF signal generator, a radio receiver capable of detecting FM signals, and an output signal level indicator.

Pulse modulation of radar and radio signals can be measured by waveform displays presented by basic oscilloscopes or synchroscopes. The amount of usable energy in a pulsed waveform, as measured by a spectrum analyzer, is also an indication of the quality of pulse modulation.

WAVEFORM MEASUREMENT

Waveform measurements can be made by observing displays of voltage and current variations with respect to time, or by harmonic analysis of complex signals. Waveform displays are particularly valuable for adjusting and testing pulse generator, pulse former, and pulse amplifier circuits. The waveform visual display is also useful for determining signal distortion, phase shift, modulation factor, frequency, and peak-to-peak voltage.

The cathode-ray oscilloscope is commonly used for the analysis of waveforms generated by electronic equipment. Several types of cathode-ray oscilloscopes are available for making waveform measurements. The oscilloscope required for a particular test is determined by characteristics such as the input frequency response, the input impedance, the sensitivity, the sweep rate, and the methods of sweep control. The synchroscope is an adaptation of the cathode-ray oscilloscope which features a wideband amplifier, triggered sweep, and retrace blanking circuits which are desirable for the analysis of pulse waveforms.

Oscilloscopes are also incorporated in some harmonic analysis test equipment to display harmonic energy levels on a cathode-ray tube. To effectively analyze waveform displays, the correct waveshape must be known beforehand. This information can be obtained from technical manuals for the equipment or from previous measurements of the same circuits when they are operating correctly.

Harmonic analysis test sets can be used to determine the energy distribution in electrical signals. Frequency-selective circuits separate the signals into narrow frequency bands, and the energy in each band is indicated by a meter or displayed on a cathode-ray tube. A group of frequency-selective circuits can be connected in parallel, a single frequency-selective circuit can be tuned manually or automatically, or a heterodyne method (using a sweep generator and fixed-tuned circuit) can be used to select electrical power present in a narrow frequency band.

The panoramic adapter is a common harmonic analyzer used in conjunction with a radio receiver to present the energy distribution of radio signals. This equipment provides a visual indication of the power present in the carrier and sideband of radio signals. Spectrum analyzers are used for the tuning and maintenance of radar transmitters to determine whether the transmitted power is concentrated in a usable frequency band. The spectrum analyzer and the panoramic adapter normally use the heterodyne method to select frequency bands and a cathode-ray tube to display the signal strength with respect to frequency.

TEKTRONIX TYPE 422 OSCILLOSCOPE

The Tektronix type oscilloscope (fig. 5-47) is a transistorized portable oscilloscope capable of operating in a wide range of environmental conditions. The type 422 is lightweight and small, making it easily transported while providing accurate measurements. The dual channel (channels 1 and 2) has a frequency response of d.c. to 15 MHz and provides calibrated deflection factors from 0.01 to 20 volts/division. Stable triggering over the full range of vertical frequency response is provided by the trigger circuits. The horizontal circuits are capable of a maximum sweep rate of 0.5 microseconds/division (0.05 microseconds/division using X10 magnifier).

The oscilloscope can be powered from a variety of power sources by using a detachable power supply section. With the type 422 a-c power supply the oscilloscope can be operated from an a-c source. Using a type 422 a-c/d-c power supply, the oscilloscope can be operated from either a-c or d-c power supplies or internal batteries.

Operation

Figure 5-48 shows the front panel controls and connectors. Table 5-1 lists the operating panel controls and connectors used in the operation of the Tektronix Type 422 oscilloscope. Column 1 lists the number as illustrated in figure 5-48; column 2 lists the control; and column 3 lists the function and operation of the control.

SYNCHROSCOPE

The synchroscope, which is widely used in radar testing, is an adaptation of the oscilloscope. A trace is produced only when it is initiated by an input trigger, as contrasted with the continuous sawtooth sweep provided by the oscilloscope. Synchroscope circuits are similar to oscilloscope circuits except for the signal channel and the sweep channel. These circuits are shown in block diagram form in figure 5-49.

The signal channel of a typical synchroscope includes an input circuit, which is usually in the form of a 72-ohm adjustable-step attenuator. Various degrees of attenuation are available, and the dial is calibrated to indicate how much attenuation is present. The attenuator insures that all signals, regardless of amplitude, produce

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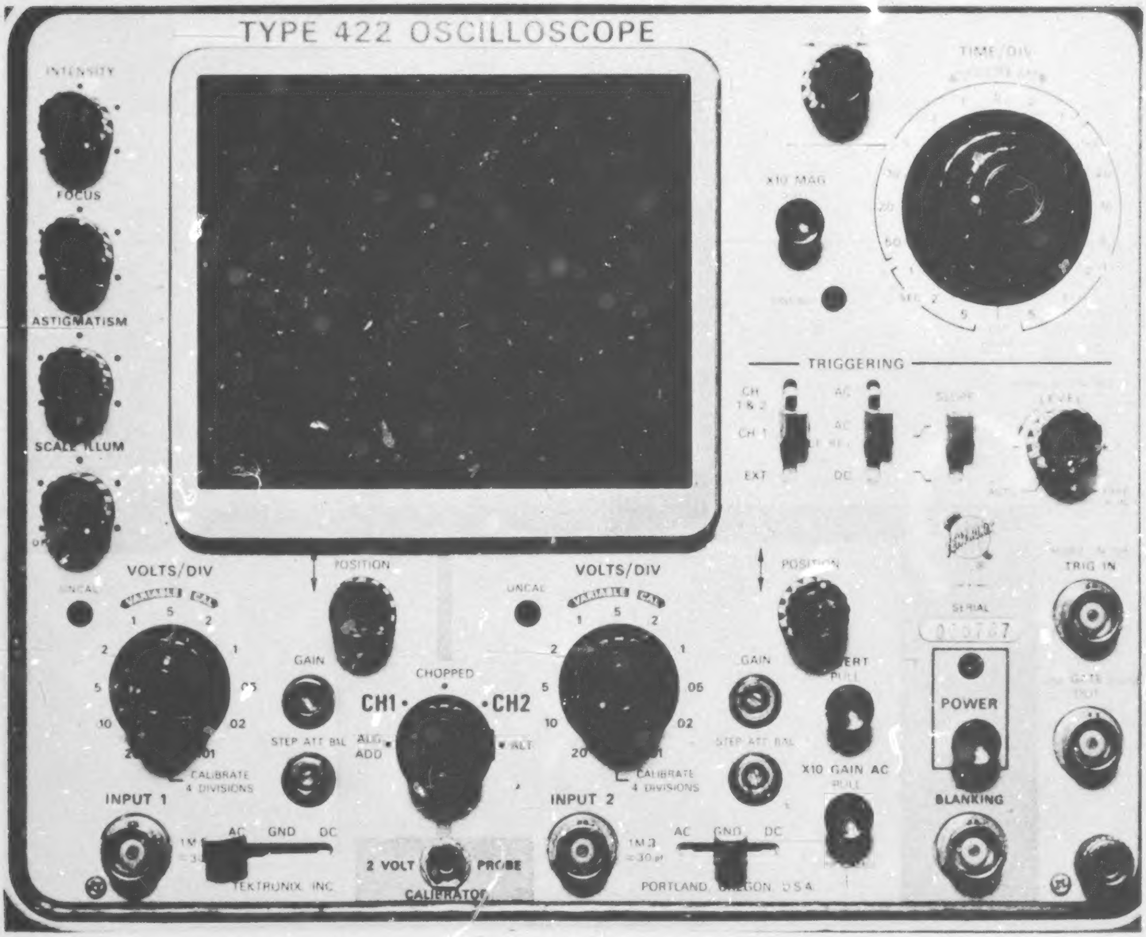
TYPE 422 OSCILLOSCOPE
INTENSITY
FOCUS
ASTIGMATISM
SCALE ILLUM
VOLTS/DIV
UNCAL
VARIABLE
CAL
POSITION
GAIN
STEP ATT BAL
CALIBRATE 4 DIVISIONS
INPUT 1
CHOPPED
CH1
CH2
ALT
ADD
INPUT 2
AC
GND
DC
2 VOLT
PROBE
CALIBRATOR
TEKTRONIX, INC.
PORTLAND, OREGON, U.S.A.
TIME/DIV
X10 MAG
TRIGGERING
EXT
SLOPE
LEVEL
X10 GAIN AC
PULL
SERIAL
POWER
BLANKING
TRIG IN

AQ. 604

Figure 5-47.—Tektronix Type 422 oscilloscope.

approximately the same input level to the amplifier section.

Following the attenuator is an artificial delay line, which is a low pass filter with a cutoff frequency higher than the highest frequency to be passed, and which has an impedance of 72 ohms. The delay line is terminated with a 72-ohm gain control. One purpose of the delay line is to delay presentation of the signal to be observed until the sweep trace has been initiated by an undelayed portion of the input signal. If the delay line were not used, the initial portion of the waveform would not appear on the trace, because a certain amount of time is required for the input signal voltage to rise to the level needed to trigger the sweep circuit. With the delay line in use, the signal does not reach the amplifier until one-half microsecond after the trace starts; as a result, the entire pulse is seen. A secondary purpose of the delay line is to

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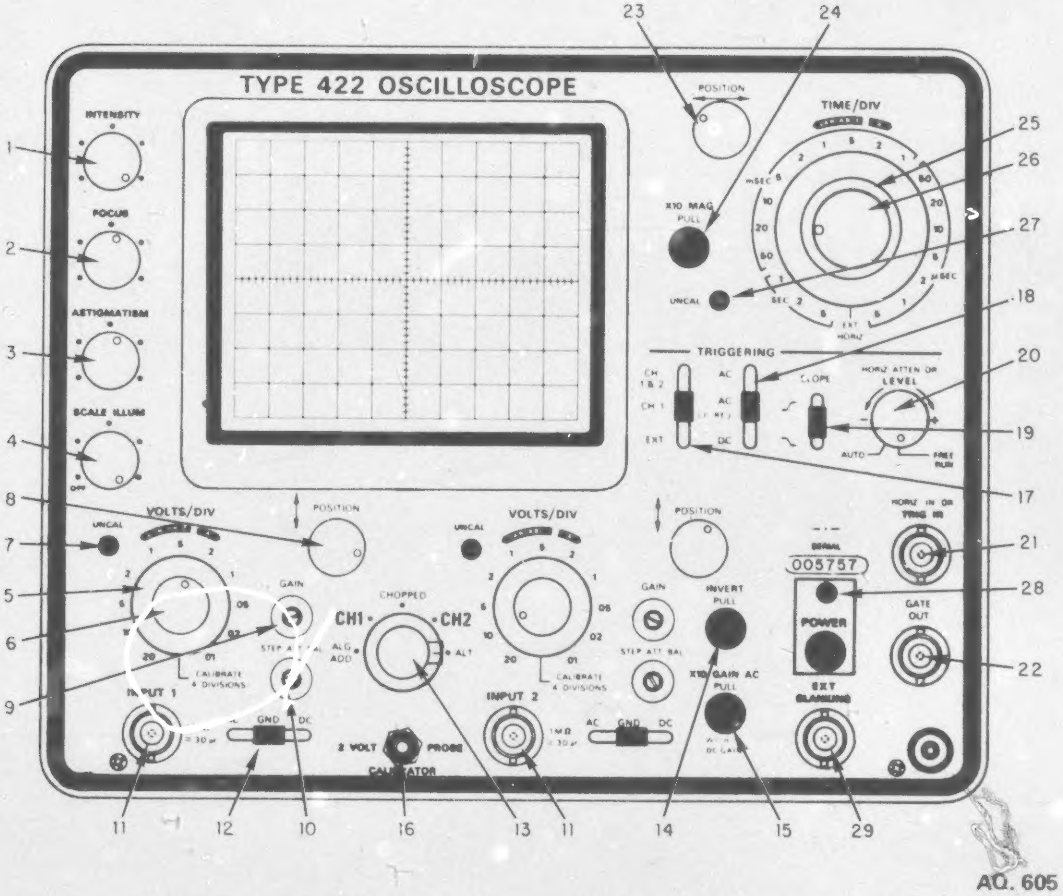
TYPE 422 OSCILLOSCOPE
INTENSITY
FOCUS
ASTIGMATISM
SCALE ILLUM
OFF
UNCAL
VOLTS/DIV
POSITION
GAIN
STEP ATT BAL
CALIBRATE 4 DIVISIONS
INPUT 1
GND
DC
CHOPPED
CH1
CH2
ALG ADD
ALT
2 VOLT
PROBE
CALIBRATOR
INPUT 2
AC
INVERT PULL
X10 GAIN AC PULL
SERIAL
005757
POWER
EXT BLANKING
GATE OUT
HORIZ IN OR TRIG IN
TRIGGERING
CH 1 & 2
CH 1
EXT
AC
AC (LF REJ)
DC
SLOPE
HORIZ ATTEN OR LEVEL
AUTO
FREE RUN
TIME/DIV
X10 MAG PULL
mSEC
μSEC
SEC
EXT HORIZ
1
2
3
4
5
6
7
8
9
10
11
12
13
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AO. 605

Figure 5-48.—Tektronix Type 422 oscilloscope front panel controls and connectors.

provide, by means of reflection, a series of accurately spaced pulses suitable for calibration of short time intervals.

To accomplish the secondary purpose, a switch is provided to cause a mismatch in the termination of the delay line. When a sharp pulse is applied into the line, a series of reflections occurs similar to those shown in figure 5-50. Since the time required for a pulse to travel down the line and back is 1 microsecond, a series of pulses occurring 1 ~~micro~~second apart is produced. Each successive pulse is smaller because of the losses in the delay line, but enough pulses are visible for most high speed calibration purposes.

The gain control feeds a wideband or video amplifier, which is connected to the vertical deflection plates. In addition, an external connection is provided to the vertical plates.

The horizontal circuit consists of a sync switch for either internal or external sync, a sync amplifier with a gain control, and a start-stop sweep generator, which will not develop a sweep voltage until a pulse of sufficient amplitude is supplied. The duration of the sweep, or sweep speed, is made adjustable from

Table 5-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 5-48).

Number	Control	Function/operation
1	INTENSITY	Controls brightness of display.
2	FOCUS	Provides adjustment to obtain a well-defined display.
3	ASTIGMATISM	Used in conjunction with the FOCUS control to obtain a well-defined display.
4	SCALE ILLUM	Controls illumination of graticule.
5	VOLTS/DIV	Selects vertical deflection factor (VARIABLE control must be in CAL position for indicated deflection.)
6	VARIABLE	Provides continuously variable deflection factor to about 2.5 times setting of the VOLTS/DIV switch.
7	UNCAL	Light indicates that VARIABLE control is not set to CAL.
8	POSITION	Controls vertical position of the display.
9	GAIN	Screwdriver adjustment to set the gain of the vertical input amplifier.
10	STEP ATT BAL	Screwdriver adjustment to set the balance of the input amplifier in the .02, .05, and .1 positions of the VOLTS/DIV switch.
11	INPUT	Input connector for vertical deflection signal.
12	AC GND DC	Selects method of coupling input signal to grid of input amplifier. AC: D-C component of input signal is blocked. Low frequency limit (-3 db point) is about 2 hertz. GND: Input circuit is grounded (does not ground applied signal). DC: All components of the input signal are passed to the input amplifier.

Table 5-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 5-48)—Continued.

Number	Control	Function/operation
13	Mode	Selects vertical mode of operation. ALG ADD: Channel 1 and 2 signals are algebraically added and the algebraic sum is displayed on the CRT. CH 1: The Channel 1 signal is displayed. CHOPPED: Dual trace display of signal on both channels. Approximately -4 microsecond segments from each channel displayed at a repetition rate of about 100 kilohertz. CH 2: The Channel 2 signal is displayed. ALT: Dual trace display of signal on both channels. Display switched between channels at end of each sweep.
14	INVERT	Inverts the Channel 2 display when pulled out.
15	X10 GAIN AC	Increases a-c gain of Channel 2 amplifier 10 times when pulled out (decreases deflection factor 10 times).
16	2-VOLT PROBE	Output connector providing 2-volt square wave signal for compensating and checking gain of a probe.
17	Source	Selects source of trigger signal. CH 1 & 2: Internal trigger signal obtained from displayed channel(s). CH 1: Internal trigger signal obtained only from Channel 1. EXT: Sweep triggered from signal applied to TRIG IN connector.

Table 5-1.–Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 5-48)–Continued.

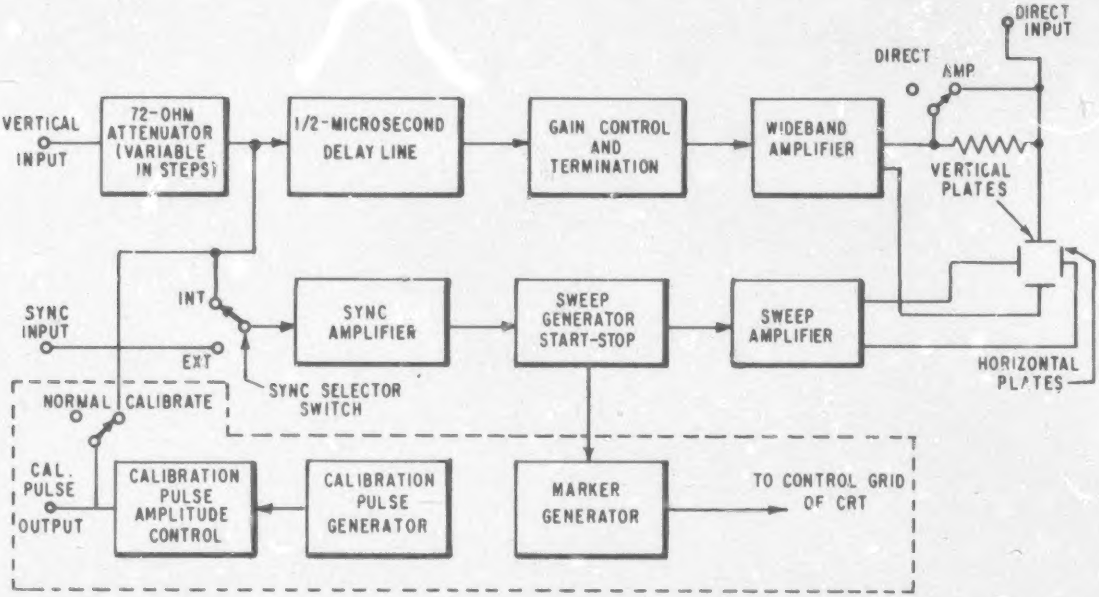
Number	Control	Function/operation
18	Coupling	Determines method of coupling trigger signal. AC: Rejects d-c signals and attenuates signals below about 50 hertz. AC LF REJ: Rejects d-c signals below about 50 kilohertz. DC: Accepts both a-c and d-c signals.
19	SLOPE	Selects portion of trigger signal which triggers sweep. _/‾ : Sweep triggered from positive-going portion of trigger signal. ‾_ : Sweep triggered from negative-going portion of trigger signal.
20	LEVEL	Selects amplitude point on trigger signal where sweep is triggered. When turned fully counterclockwise to the AUTO position, the sweep is automatically triggered. In the FREE RUN position, fully clockwise, the sweep free runs.
	HORIZ ATTEN	(Triggering LEVEL) Provides approximately 10.1 attenuation for external horizontal signals connected to the HORIZ IN connector when the TIME/DIV switch is set to EXT HORIZ.
21	TRIG IN	Input connector for external trigger signal.
	HORIZ IN	(TRIG IN) Input connector for external horizontal signal when TIME/DIV switch is set to EXT HORIZ.
22	GATE OUT	Output connector providing a 0.5 volt or greater negative-going rectangular pulse which is time-coincident with the sweep.

Table 5-1.–Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 5-48)–Continued.

Number	Control	Function/operation
23	POSITION	Controls horizontal position of the display.
24	X10 MAG	Increases sweep rate to 10 times setting of TIME/DIV switch by expanding center division of the display.
25	TIME/DIV	Selects sweep rate of the sweep circuit (VARIABLE control must be in CAL position for indicated sweep rate). In the EXT HORIZ position, horizontal deflection is provided by a signal connected to the HORIZ IN connector.
26	VARIABLE	Provides continuously variable sweep rate to at least 2.5 times setting of the TIME/DIV switch. Sweep rate is calibrated only when control is set fully clockwise to the CAL position.
27	UNCAL	Light indicates that VARIABLE control is not set to CAL.
28	POWER	Light: Indicates that POWER switch is on and the instrument is connected to a power source. Switch: Applies power to the instrument.
29	EXT BLANKING	Input connector for external blanking signal.

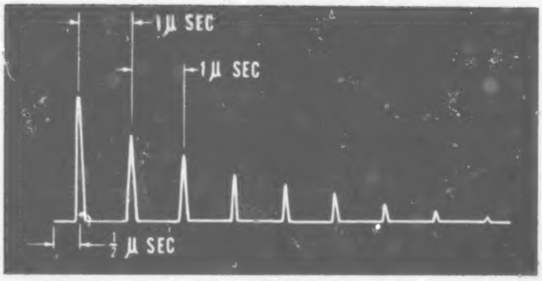
a very few microseconds to about 250 microseconds. The sweep generator is followed by a conventional horizontal amplifier. Since the trace is triggered by the input signal, the synchroscope may be used to observe nonperiodic pulses, such as those occurring in a radar system with an unstable PRF generator.

In later designs, it is common to find provisions for calibration of input voltages and sweep time. Voltage calibration is made by comparing the unknown voltage with a variable-voltage pulse of known value, generated internally. The calibrating pulse is adjusted to be equal in amplitude to the unknown voltage; the value is then read from the dial that controls the calibrating pulse. Sweep time calibration is made


DIRECT INPUT
DIRECT
AMP
VERTICAL INPUT
72-OHM ATTENUATOR (VARIABLE IN STEPS)
1/2-MICROSECOND DELAY LINE
GAIN CONTROL AND TERMINATION
WIDEBAND AMPLIFIER
VERTICAL PLATES
INT
SYNC INPUT
EXT
SYNC AMPLIFIER
SWEEP GENERATOR START-STOP
SWEEP AMPLIFIER
HORIZONTAL PLATES
SYNC SELECTOR SWITCH
NORMAL
CALIBRATE
CAL. PULSE OUTPUT
CALIBRATION PULSE AMPLITUDE CONTROL
CALIBRATION PULSE GENERATOR
MARKER GENERATOR
TO CONTROL GRID OF CRT

AT. 131

Figure 5-49.—Typical synchroscope, block diagram.


1µ SEC
1µ SEC
½ µ SEC

AT. 132

Figure 5-50.—Pulse reflection on a mismatched line.

with the aid of marker pulses produced by accurately adjusted tuned circuits. The marker pulses appear on the trace as a series of bright dots spaced at intervals chosen by the operator. In a typical synchroscope, marker intervals of 0.2, 1, 10, 100, and 500 microseconds may be selected in accordance with the time duration of the pulse under test; for greater accuracy, interpolation may be used.

SPECTRUM ANALYZER

During the modulation of a radiofrequency carrier wave by keying, by speech or music, or by pulses, the resulting wave contains many frequencies. The original carrier is present, together with two groups of new frequencies called the sideband components. One group of sidebands is displaced in frequency below the carrier. The other group is displaced above the carrier. The distribution of these frequencies when shown on a graph of voltage or power against frequency is called the spectrum of the wave.

A spectrum analyzer is a device for exhibiting the spectrum of modulated waves in the radiofrequency range and in the microwave region.

In principle, the spectrum analyzer operates by tuning through the frequency region in question, using a narrowband receiver. The output of the receiver is measured, usually by means of a cathode-ray oscilloscope, and the plot on the screen is a graph of voltage versus frequency.

The device is essentially a superheterodyne receiver with a very narrowband intermediate frequency amplifier section. The local oscillator frequency is varied between two values at a linear rate. The frequency-control generator which governs the frequency of the local oscillator also produces the horizontal sweep voltage for the cathode-ray tube deflection plates. (See fig. 5-51.) As a result, each position of the beam corresponds to a definite frequency value; and the display is a graph in which the X-axis is interpreted in terms of frequency.

The output of the detector in the receiver is amplified and applied to the vertical deflection plates so that the beam is deflected vertically by an amount proportional to the voltage developed in the detector (and amplifier).

The signal to be analyzed is fed into the mixer stage of the receiver. The local oscillator changes in frequency at a linear rate, beating with each of the signal frequency components in succession to form the intermediate frequency of the narrowband amplifier. The output of the IF amplifier is detected, amplified, and applied to the vertical deflecting plates.

Spectrum analyzers designed for analysis of microwave signals are equipped with klystron tubes in the local oscillator stage. In analyzers adapted for lower frequency RF signals, triode oscillators are used which are varied by means of reactance-tube modulators.

Spectrum analyzers are employed extensively in studying the output of pulse radar transmitter tubes such as the magnetron. In this kind of analysis, unwanted effects such as frequency modulation of the carrier can be easily detected. In pure amplitude modulation of a carrier wave by a square pulse, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation.

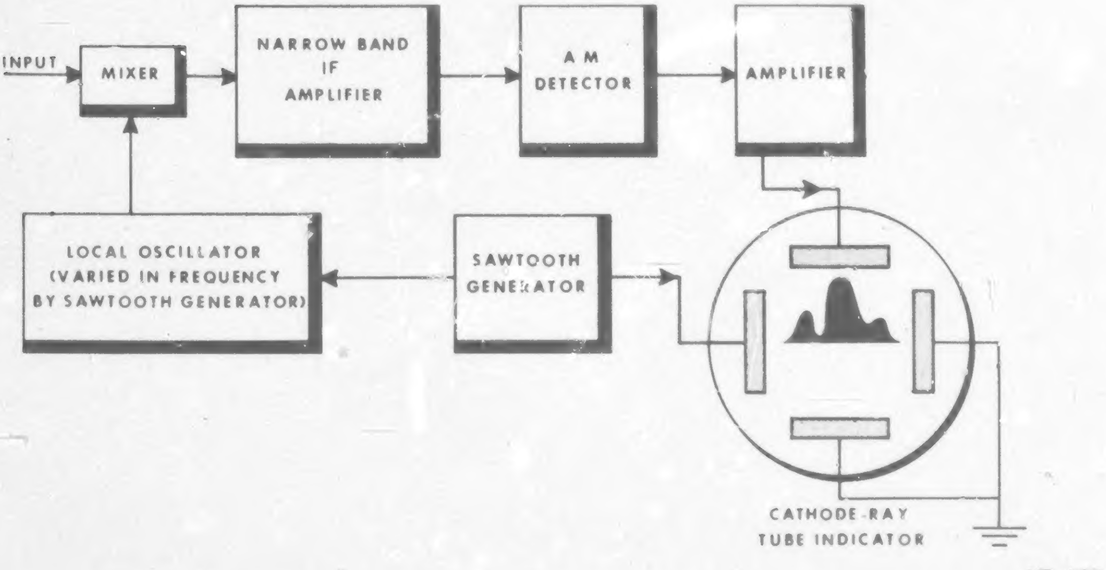

INPUT
MIXER
NARROW BAND IF AMPLIFIER
A M DETECTOR
AMPLIFIER
LOCAL OSCILLATOR (VARIED IN FREQUENCY BY SAWTOOTH GENERATOR)
SAWTOOTH GENERATOR
CATHODE-RAY TUBE INDICATOR
AT. 133

Figure 5-51.—Typical spectrum analyzer, block diagram.

A spectrum representing the ideal condition is shown in (A) of figure 5-52.

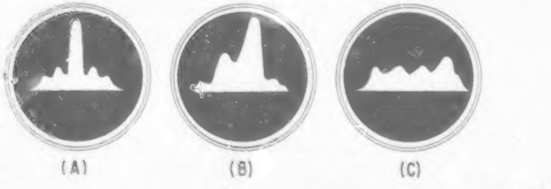
Examples of undesirable magnetron spectra are shown in (B) and (C) of figure 5-52. These forms indicate trouble in the modulator, the tuning system, or in the magnetron tube itself.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 5-52. In some analyzers this principle is used as a means of carrier frequency measurement. A sharply resonant circuit is provided in the receiver which acts as a trap to prevent an extremely narrow range of frequencies from appearing in the output of the IF amplifier. The result of its use is that a gap appears in the display, and the gap corresponds to the resonant frequency of the trap. The adjustment of the trap is calibrated in frequency, and the circuit can be adjusted to make the gap occur in the center of the spectrum. The frequency of the carrier is then read from the calibration of the trap.

WAVE ANALYZER

The wave analyzer is used to measure amplitude and frequency of the components of a steady state complex electrical waveform. These include the components of harmonic distortion, intermodulation distortion, hum, and noise.

Specific uses of the wave analyzer include the measurements of distortion components in AF equipments; radio receivers and transmitters; oscillators, amplifiers, and vacuum tube circuits in general; harmonic studies of electrical power system and electrical machinery; hum measurement in a-c operated communication equipment; and noise analysis. As a sharply tuned voltmeter, it is useful in the measurement of the transmission characteristics of electric wave filters and as a null detector for impedance bridges. The unit may be used as a detector for intermodulation distortion measurements when a two-signal audio generator is used as a source.


(A) (B) (C)

AT. 134

Figure 5-52.—Frequency spectra.

The wave analyzer discussed in the following paragraphs is a heterodyne type vacuum tube voltmeter. The IF amplifier includes a selective filter using three quartz crystals. The use of a heterodyne method makes it possible to vary the frequency response while using a fixed frequency filter.

The output of the local oscillator and the whole of the complex waveform to be examined are fed to a balanced modulator where their combination produces both sum and difference frequencies, or sidebands in the output. The original of the complex waveform is not passed by the modulator intermediate frequency output transformer and the local oscillator carrier frequency is suppressed in the output because of the two-tube, balanced modulator employed.

The 50-kHz component of the upper sideband, proportional to the voltage of that frequency present in the original wave to which the main dial is set, is selected and amplified by the intermediate stages. The step attenuators provide for measurement of a wide range of voltages.

The equipment is mounted in a shielded oak cabinet, and all critical parts are hermetically sealed.

A detailed discussion of wave analyzers is beyond the scope of this training manual, but the foregoing discussion should serve to familiarize the technician with some of the basic principles used in the design of a wave analyzer.

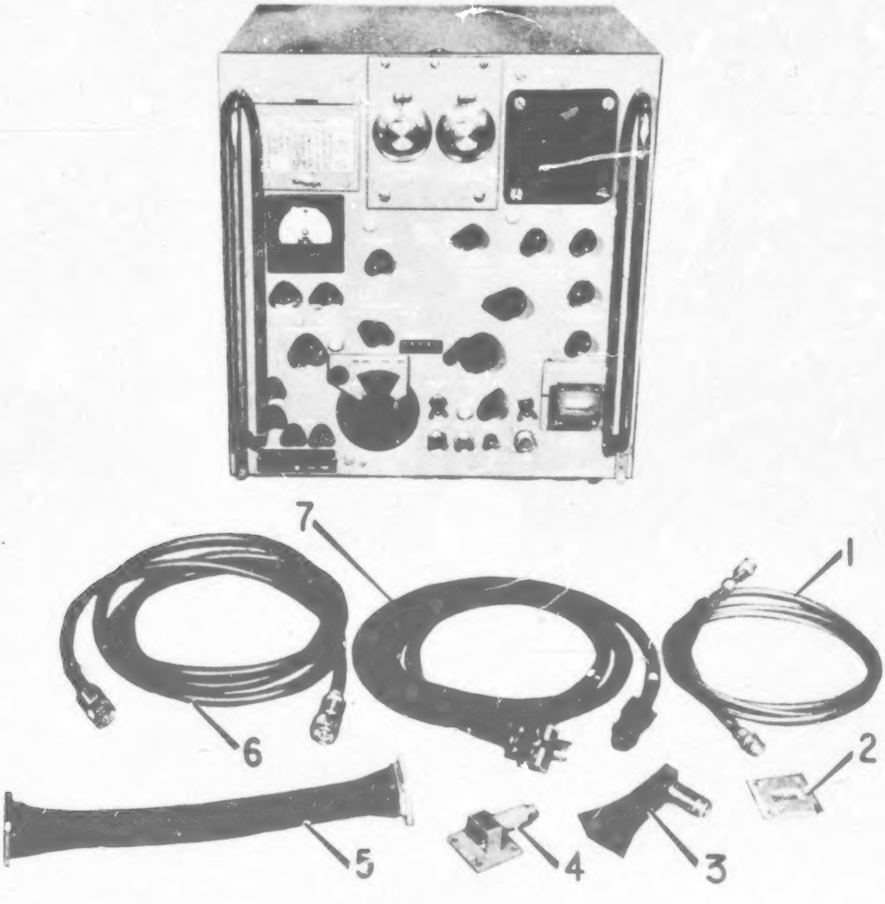
MULTIPLE-FUNCTION EQUIPMENT FOR SYSTEMS TESTING

The numerous and complex operations required for servicing and maintaining radar requires, in some instances, numerous classes of test equipment. Therefore, a test set such as the UPM-32, combining the functions of several test sets, is very practical. This combination test set performs most of the functions necessary for radar maintenance in its frequency range.

This test equipment (fig. 5-53) is portable and is designed primarily for use with radar systems operating in the frequency range of 8,500 to 10,500 MHz. It functions as a power meter, a frequency meter, a spectrum analyzer, a signal generator, and a general purpose synchroscope. The general capabilities of the test set are as follows:

1. Measurement of power, frequency, spectrum, and frequency pulling of conventional and multipulsed radar transmitters.
2. Measurement of sensitivity and bandwidth of a radar receiver.
3. Measurement of the frequency and spectrum of a radar receiver's local oscillator.
4. Adjustment of a radar receiver's local oscillator.
5. Measurement of TR recovery time.
6. Observation of video signals.
7. Providing pulsed, FM, or CW microwave signals.

Radar Test Sets AN/UPM-32 and AN/UPM-



AT. 135

1. Cable assembly.
2. Gaskets.
3. Test antenna.
4. Adapters.
5. Waveguide.
6. RF cable.
7. Power cable.

Figure 5-53.—Radar Test Set UPM-32.

44C are very similar in function and in operation. Each is usable for the same general functions. Both are generally reliable instruments, but are susceptible to mixer crystal damage due to improper manipulation of the control. For this reason, every technician should receive a thorough indoctrination in the proper use and operation of these equipments when they are available in his particular shop. Although this requirement is generally applicable for all test equipment (and other electronic equipments), it is especially important in equipments where the probability of damage from improper operating procedures is so great.

LINE SUPPORT EQUIPMENT

The purpose of this section is to discuss some of the more common test sets that are used during line maintenance by organizational maintenance activities. It is not intended that this discussion be all inclusive of all line test equipment, but only some of the more common line test sets.

The majority of line test equipment are of the GO - NO GO type. In other words, the test set indicates that the electronic system under test does or does not meet the minimum acceptable standard. Some of the more intricate line test equipment can be used to determine faulty units (black boxes) of a system. Operational tests of a system after installation of a repaired unit may also be made with this type of test equipment.

IFF

Radar Test Set AN/UPM-8B is a portable, a-c operated instrument, designed to perform rapid preflight checks of installed transponders, such as those of the Mark X IFF system. Its testing capabilities include checking the above transponders when they are operated in association with Selective Identification Feature (SIF) coding equipment, such as Coder Group AN/APA-89. The following features of transponders or associated SIF equipment can be checked simultaneously:

1. Transmitted frequency.
2. Relative transmitter power output.
3. Decoding of mode 1, 2, or 3 interrogations (challenges).
4. Reply coding (number but not spacing of pulses for Mark X).
5. Receiver frequency.
6. Relative receiver triggering level.
7. Proper code configurations (when SIF equipment is employed).
8. Pulse spacing (when SIF equipment is employed).

The results of these checks are simultaneously resolved into a single REJECT or ACCEPT indication of an operating panel meter. The REJECT-ACCEPT meter on the operating panel may also be used to give an indication of the general operating condition of the test set itself.

TACAN

Radio Test Set AN/URM-101A is a lightweight, easy-to-use unit developed to provide preflight check of the normal operation of airborne TACAN sets. The test set may be hand-carried to the vicinity of the aircraft equipped with the radio set and placed on the deck, or any other suitable support. During operation of the test set, visual and aural indications at the radio set will enable an observer to determine whether the radio set is operating properly. The test set receives from and transmits to the TACAN radio set either by radiation from the antenna or by a direct connection with a coaxial cable. The test set will operate with up to four TACAN radio sets simultaneously.

The test set simulates signals such as those produced by Radio Beacon Set AN/URN-3, and which would normally be received by airborne TACAN sets at a particular bearing and distance from the beacon set. The test set generates a continuous tone signal, which provides aural indication when received. The test set transmits a continuous pulse train consisting of main and auxiliary reference pulse groups (bursts), identity pulses, and equalizing pulses. In addition, when interrogated, it introduces reply pulses delayed to simulate distances of 5 miles and 100 miles. All of these pulses are amplitude-modulated with 15 and 135 hertz sine waves and are synchronized to give a bearing display of 140° on the airborne azimuth indicating equipment. A power output level control adjusts the RF unit to a constant power output, which is indicated on a panel meter. A range switch sets the desired 5-mile or 100-mile delay.

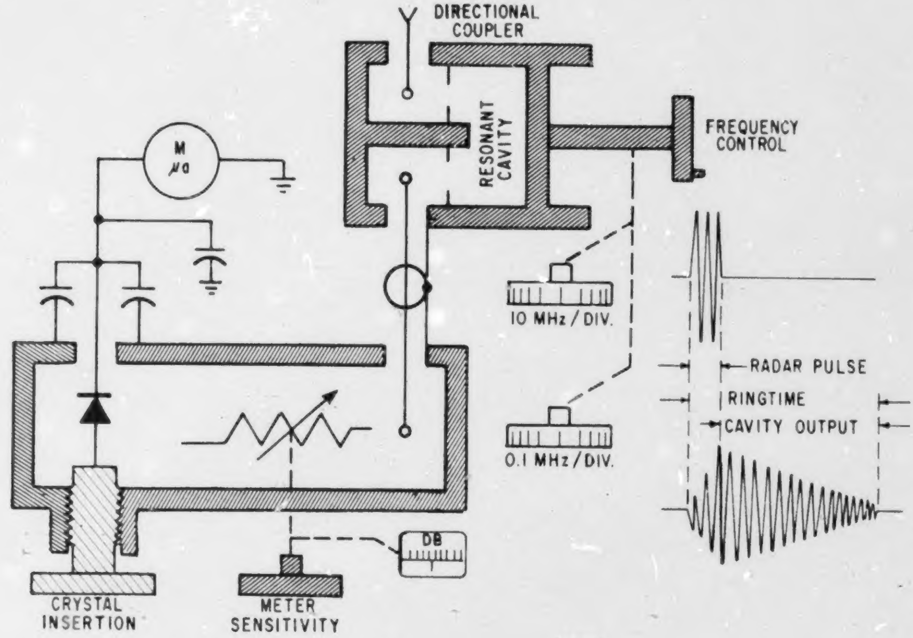
RADAR

The echo box is used in field testing, troubleshooting, and adjustment of pulsed type radar systems. Although simple in construction and operation, it is versatile in its applications. Properly used within its design limitations, the echo box can frequently eliminate the need for a complex test setup and an elaborate step-by-step testing procedure. The echo box uses passive circuitry, which does not require any external power (other than that of the radar set whose signal is to be analyzed). External power requirement is a critical factor with most other test sets.

The echo box is similar to a tuned cavity frequency meter, with additional capabilities. The tuned cavity frequency meter can be used to measure the frequency of CW or pulsed RF signals in the microwave range. The echo box, however, has no practical application in the testing or analysis of CW equipment signals. Figure 5-54 indicates the basic functional elements of a typical echo box.

Energy from the radar transmitter is fed through the directional couplers to the resonant cavity. When the cavity length is properly adjusted, resonant oscillations are set up by each successive pulse of microwave energy. Maximum amplitude of oscillation occurs when the cavity is tuned precisely to the signal frequency. These cavity oscillations are detected by the crystal diode and indicated on the meter as an average d-c current. The amplitude of oscillation and the average current reading are proportional to the transmitter power output.

Oscillations in the tuned cavity are also coupled back to the radar set under test, where it is processed as an echo signal. This signal,



AT. 136

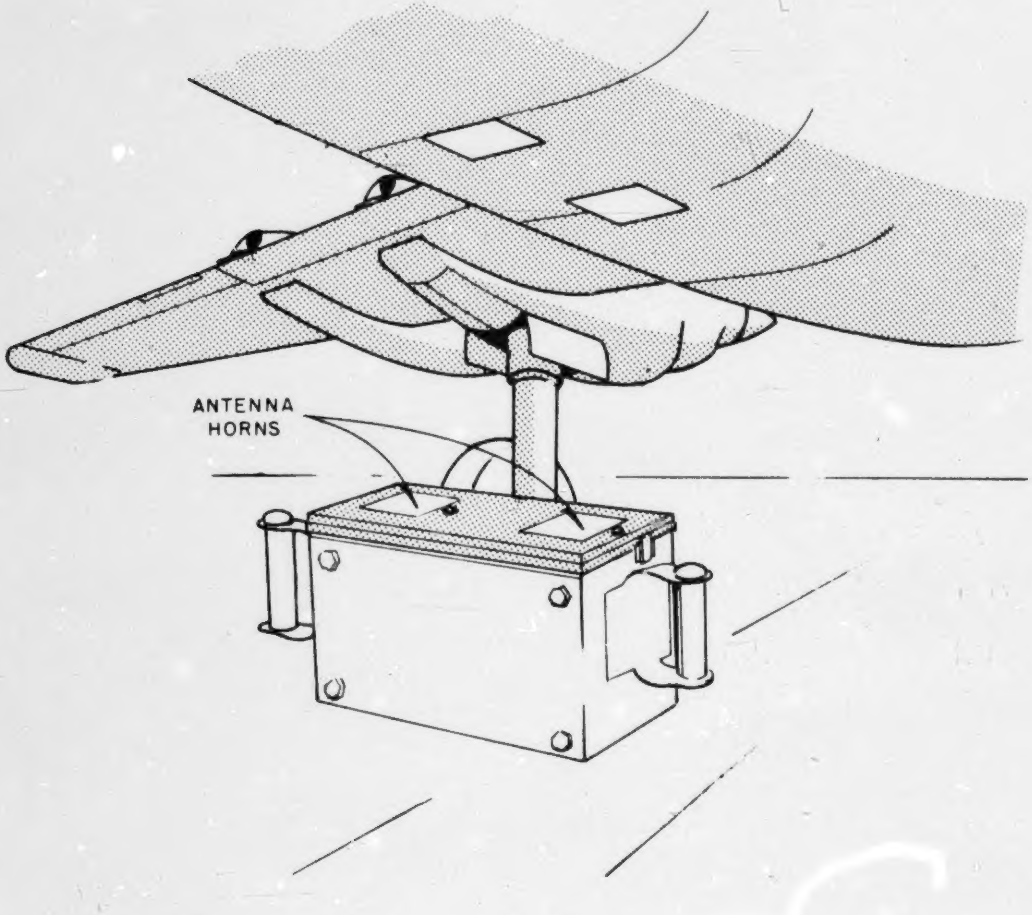
Figure 5-54.—Typical echo box, functional circuit.

when viewed on the indicator CRT, permits analysis of the radar pulse, and presents an indication of the general operating condition of the radar set.

Due to the manner in which the energy builds up in the cavity, saturation of the cavity is possible. If saturation does occur, distortion of the waveform and erroneous values of the measurements result. If the directional couplers do not prevent cavity saturation, additional attenuation must be provided.

A fairly complete functional analysis of the operating condition of a radar set can be obtained through analysis of the displayed waveform. Among the most important of the factors that can be determined are frequency and bandwidth, power and frequency spectra, sensitivity, pulse width and condition, and recovery time. Analysis of the waveform can also prove helpful in locating the cause of malfunctions within the radar set.

It must be remembered, however, that the echo box presents only relative (rather than absolute) values of power and sensitivity, and only rough values of frequency. Accuracy of these quantities is not comparable to the cor-



AT. 137

Figure 5-55.—Delay line MX-1381/APM-66.

responding values obtainable from a spectrum analyzer. The primary value of the echo box lies in its regular usage. For maximum benefit, the values obtained from a given test must be compared to corresponding values obtained from a test on a radar set known to be operating properly.

In general, however, the echo box is an extremely valuable instrument. When used in a continuing maintenance program, it can enable the operator to maintain his equipment in peak operating condition. It can also provide him with indications of deterioration before actual malfunctions occur.

ALTIMETER

Delay Line MX-1381/APM-66 (fig. 5-55) is a portable unit of the Radar Test Set AN/APM-66 and consists of a coaxial cable delay line and two horn-type antennas. The two horns are connected together by a length of RG-55/U cable that is wound on two drums within the unit.

When the delay line unit antennas are mated with the altimeter receiver-transmitter antennas, the RF output of the transmitter is fed into one of the horn antennas, passes through the coaxial cable to the other antenna, and is fed out to the receiving antenna of the altimeter where it arrives delayed in time by an amount that is equal to the propagation time (electrical length) of the coaxial cable. This produces an altitude signal in the altimeter that is identical to that produced in normal altimeter operation when the altimeter is at an altitude that yields the same total propagation time down to the terrain and back again. Since two-way propagation is involved in normal operation, the altitude signal produced by a delay line will be equal to one-half the electrical length of the cable.

The length of the coaxial cable requried for a delay line of this type may be determined from the formula:

L = VX altitude X 2

Where

L = phsycial length of the cable

V = velocity of wave propagation of the cable.

The delay line contains 228 feet of cable (330 electrical feet) and produces an altitude signal of 165 feet. The total attenuation of the cable and the two antenna horns is such that the altimeter that produces an altitude indication of 165 feet, minus the residual altitude, when coupled to the delay line can be considered as having adequate sensitivity for normal flight operation.

CHAPTER 6

AVIONICS MAINTENANCE

In today's modern aircraft, the aviation weapon systems that are contained in them must be in top operating conditions at all times to insure that the aircraft can complete the mission for which it is designed. The effectiveness of this weapon system depends primarily on the technicians assigned to maintain them. These technicians are only as good as the handtools they use, the publications they use, and last but not least their knowledge of general as well as specific maintenance procedures. In this chapter, general maintenance procedures will be covered that will apply to most avionics systems found in aircraft today.

TROUBLESHOOTING

Much of the technician's time is spent troubleshooting the equipment in the squadron's aircraft. The technician's job is to maintain a great number of units and systems, many of which are quite complex, and which might seem at a glance beyond his ability to maintain. However, the most complex job usually becomes much simpler if it is first broken into successive steps. Any maintenance job should be performed in the following order:

1. Analyze the symptom.
2. Detect and isolate the trouble.
3. Correct the trouble and test the work.

AIRCRAFT PROCEDURES

In troubleshooting, as in most other things, there is no substitute for commonsense. A mistake made by most beginners is to remove major units from the aircraft unnecessarily. When a discrepancy is received, the first step is to determine if the equipment in question is actually faulty. Very often a preliminary check of the system in the aircraft will disclose a faulty control box, frayed or broken wiring, corroded or wet connectors, or improper operating procedure—especially with new equipment. (Improper operating procedures are especially common when the reported discrepancy involves new equipment or personnel undergoing indoctrination.)

If there is no power present at the input to the equipment, it may be assumed (temporarily) that the set is not defective. Check all applicable switch positions, circuit breakers, fuses, etc., then check for power at the bus which feeds the equipment. Check the tightness and the physical condition of interconnecting cables. Using the wiring diagrams in the applicable manuals, check at successive tie points and splices for continuity, short circuits, or grounds. The procedures to be followed with these tests are discussed later in this chapter under the heading Basic Tests.

If a circuit breaker is tripped or if a fuse is blown, a circuit malfunction is indicated. Power to the circuit containing the "open" should be turned off, and should not be reapplied until the malfunction is located and corrected. The most common causes of tripped or blown circuit protectors are short circuits, faulty grounds, or overload conditions. However, circuit protectors sometimes fail due simply to age or to transient conditions. If, after a thorough check, no apparent reason for the failure can be found, the breaker may be reset or the fuse replaced with the proper size and type, and the power reapplied. If the protector fails again, a malfunction is definitely indicated.

If the analysis does not indicate the existence of a short circuit, faulty ground, or overload condition, but the equipment still does not operate, continue to take measurements with power applied. These measurements should be taken systematically at progressive checkpoints. Particular faults which may interrupt current through a circuit include broken wiring, loose or faulty terminal or plug connections, faulty relays or switches, and uncoupled splices. Be alert for these conditions.

If the defective unit cannot be identified while still installed in the aircraft, it may be advisable to turn off the power and substitute units, one at a time with units which are known to operate properly. As each unit is replaced, power should be reapplied and the system checked for operation or for symptoms of nonoperation. If the system operates normally, the faulty unit has been identified, and the faulty unit may be taken to the work center for corrective maintenance action. At this stage of the overall maintenance process, it is also advisable to try to determine the reason for the failure of the unit—it is conceivable that the new unit may also be damaged if the basic cause of the fault is not corrected.

Following removal of the defective unit and the subsequent analysis, all other items of the original installation should be reinstalled and an operation check performed. During the operational check, any readjustments or calibrations should be accomplished as required. This should be done prior to clearing the discrepancy in the work center.

Basic Tests

Several rules are set forth below and are intended as a guide to follow when making the tests described in this section.

1. Always connect an ammeter in series.
2. Always connect a voltmeter in parallel.
3. Never connect an ohmmeter to an energized circuit.
4. Select the highest range first then switch to lower ranges as needed.
5. When using an ohmmeter, select a scale that will result in a midscale deflection.
6. Do not leave the selection switch of a multimeter in the resistance position when the meter is not in use because the leads may short together and discharge the internal battery. There is less chance of damaging the meter if it is left on a high a-c volts setting or in the off position if it has one. Meters that have an off position dampen the swing of the needle by connecting the meter movement as a generator. This prevents the needle from swinging wildly when the meter is moved.
7. View the meter from directly in front to eliminate parallax.
8. Observe polarity when measuring d-c voltage or direct current.
9. Do not place meters in the vicinity of strong magnetic fields.
10. Never attempt to measure the resistance of a meter or a circuit with a meter in it as the high current required for ohmmeter operation may damage the meter. This also applies to circuits with low-current filament tubes and some types of semiconductors.
11. When measuring high resistance, be careful not to touch the test lead tips or the circuit as body resistance will shunt the circuit and an erroneous reading will occur.
12. Connect the ground lead of the meter first when making voltage measurements. Work with one hand whenever possible.

CONTINUITY TEST.—Open circuits are those in which the flow of current is interrupted by a broken wire, defective switch, or any means by which the current cannot flow. The test used to check for opens (or to see if the circuit is complete or continuous) is called continuity testing.

An ohmmeter (which contains its own batteries) is excellent for a continuity test. In an emergency, a continuity tester can readily be constructed from a flashlight. Normally, continuity tests are performed in circuits where the resistance is very low (such as the resistance of a copper wire). **An open circuit is indicated by a** very high or infinite resistance.

The diagram in figure 6-1 shows a continuity test of a cable. Notice that both connectors are disconnected and the ohmmeter is in series with the conductor under test. The power must be off. Checking conductors A, B, and C, the current from the ohmmeter will flow through plug No. 2, through the conductor, and plug No. 1. From this plug it will pass through the jumper to the chassis which is "grounded" to the aircraft's structure. The structure will serve as the return path to the chassis of unit 2 completing the circuit to the ohmmeter. The ohmmeter will indicate a low resistance.

Checking conductor D (fig. 6-1) will reveal an open. The meter will indicate maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left since it is a series type ohmmeter.

Where conditions exist that the aircraft structure cannot be used as the return path, one of the other conductors may be used. For example, to check D (fig. 6-1) a jumper is connnected from pin D to pin A of plug 1 and the ohmmeter leads are connected to pins D and A of plug 2. This technique by the process of elimination will also reveal the open in the circuit.

GROUNDED CIRCUIT TEST.–Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic framework of the aircraft. Grounds may have many causes, the most common of which is perhaps the fraying of insulation from a wire allowing the bare wire to come in contact with the metal ground.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than ground. A high resistance ground may also occur where sufficient current does not flow to rupture the fuse or open the circuit breaker.

In testing for grounds, the ohmmeter is used. Other continuity testers may also be used. By measuring the resistance to ground of any point in a circuit, it is possible to determine if the point is grounded. Figure 6-1 illustrates one possible means of testing a cable for grounds. If the jumper is removed from pin D of plug No. 1, a test for grounds is made for each conductor of the cable. This is accomplished by connecting one meter lead to ground and the other to each of the pins of one of the plugs. A low resistance will indicate that a pin is grounded. Both plugs must be removed from their units; if only one plug is removed, a false indication is possible since a conductor may be grounded through the unit.

SHORT TEST.–A short circuit, other than a

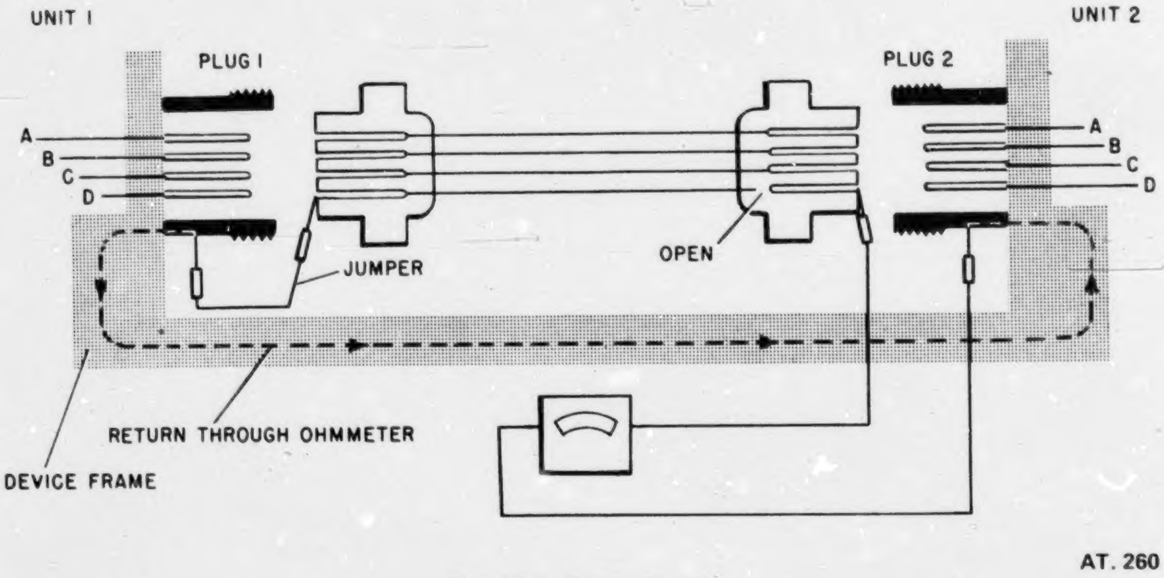


Figure 6-1.–Continuity test.

grounded one, is one where two conductors accidentally touch each other directly or through another conducting element. Two conductors with frayed insulation may touch and cause a short. Too much solder on the pin of a connector may short to the adjacent pin. In a short circuit, sufficient current may flow to blow a fuse or open a circuit breaker. However, it is entirely possible to have a short between two cables carrying signals; such a short may not be indicated by a blown fuse.

As when checking for a ground, the device used for locating a short is the ohmmeter. By measuring the resistance between two conductors a short between them may be detected by a low resistance reading. In figure 6-1 by removing the jumper and disconnecting both plugs, a short test may be made. This is performed by measuring the resistance between the two suspected conductors.

Shorts are not reserved for cables, they occur in many components, such as transformers, motor windings, capacitors, etc. The major test method for testing such components is a resistance measurement, and then comparing the indicated resistance with that given in the Maintenance Instructions.

VOLTAGE TEST.–The voltage test must be made with the power applied; therefore, the prescribed safety precautions must be followed to prevent injury to personnel and damage to the equipment. The technician will find in his maintenance work that the voltage test is of utmost importance. It is used not only in isolating faults to major components but also in the maintenance of subassemblies, units, and circuits. Before checking a circuit voltage, a check on the voltage of the power source should be made to ascertain that the normal voltage is being supplied to the circuit.

BENCH PROCEDURES

The visible condition of a unit is usually the first thing to check in any process of troubleshooting. If certain parts are obviously not in proper condition, these faults must be corrected before going any farther in the tests. Such conditions include parts which are burned, loose from their mountings, disconnected, dented, broken, or otherwise faulty. This step should be accomplished prior to installing and connecting the unit at the test bench.

The sense of smell can be helpful in pinpointing certain troubles. A part that overheats usually gives off an odor that is readily detectable, and can sometimes be located by the odor given off. However, location of a burned part does not necessarily reveal the cause of the trouble.

In determining the cause of the trouble it is usually necessary to refer to the Maintenance Instructions Manual. This manual will be a valuable source for constant reference when performing maintenance on electronic equipment. Few technicians are so thoroughly familiar with an electronic unit that they do not need the manual when performing maintenance.

Signal Tracing

The following procedure is given for tracing signals in RF receivers and audio amplifiers; however, this general procedure, with modifications, can be applied to most electronic troubleshooting. In radar the frequencies are higher, the methods of signal application differ, and the output in the final stage is video on a scope, instead of audio from a speaker or headset. The applicable Maintenance Instructions Manual contains detailed procedures for testing most units or circuits.

Signal tracing is a very effective method for locating defective stages in many types of electronic equipment. It is especially useful when working with sonobuoy receivers, audio amplifiers, and other equipment which normally do not contain built-in meters. A signal voltage (similar to that present under operating conditions) taken from a signal generator is applied to the input of the circuit in question. The signals which result are then checked at various points in the stage, utilizing test instruments such as vacuum tube voltmeters, oscilloscopes, output meters, or any high impedance instrument which is appropriate. (The test instrument should have high impedance so that it will not change the operation of the circuit under test.)

When using the signal tracing technique to measure a-c signals, be sure that the test instruments are adequately isolated from any d-c potentials present in the circuit. Some test instruments are equipped with special a-c probes which incorporates a capacitor in series with the input; other equipments are not so equipped. Before using any item of test equipment, the technician must familiarize himself with the characteristics and proper use of the test equipment, as well as with the equipment under test.

Signal tracing can be used to measure the gain or loss of amplifiers; also, the points of origin of distortion, hum, noise, oscillation, or any abnormal effect can be localized in this manner.

The gain measurement is an important method in signal tracing. By this procedure, a defective stage can be found quickly in a radio sonobuoy receiver or audio amplifier. A signal generator, with the output attenuator calibrated in microvolts, and an output meter are used. It is helpful to have data concerning the normal gain of the various stages of the device. These data are generally found in the Maintenance Instruction Manual for the receiver under test.

The output meter may be connected across a headset (or the voice coil of a speaker) or across the secondary of the output transformer. The output of the signal generator is applied to the input circuit of the stage under test. The attenuator of the signal generator is then adjusted until the output meter reads a value appropriate to serve as a reference figure. The output of the signal generator is then applied to the output of the stage under test (or to the input of the next stage), and the attenuator is adjusted until the same reference value is again registered on the output meter. The gain of the stage is found by dividing the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage.

As an example, suppose the signal generator supplies a voltage of 400 microvolts to the grid of an IF amplifier. This voltage causes the output meter to indicate some value that can be used as a reference. When the generator signal is applied to the following grid, the signal strength must be increased (to 4,000 microvolts) to cause the output meter to indicate the same reference value. The gain of the stage is equal to

$$\frac{E_{in}\text{ 2nd stage}}{E_{in}\text{ 1st stage}}\text{; that is, }\frac{4{,}000}{400} = 10$$

If similar measurements made in the remaining stages of the receiver reveal one stage in which the gain is lower than normal or is zero, that stage can then be thoroughly checked by further testing to determine the cause of the trouble.

When making stage gain measurements in receivers, the value of the applied signals must be low enough to prevent the AVC system from functioning; otherwise, the measurements will not be accurate. In the Maintenance Instruction Manual, the recommended signal values are usually stated in terms of the reference value to be used at the output meter.

Test Probe Substitution

Using a test equipment probe with equipment other than that for which it was designed may result in considerable error. Any differences in the internal resistance of the probe and the input resistance of the circuitry of the equipment precludes substitution without calibration. For example, the internal resistance of a 10:1 probe is, in most cases, nine times higher than the input circuitry of the equipment. It should be noted that 2:1, 50:1, and 100:1 probes are available as well as 10:1 probes.

Test probes which are not recommended for specific equipments should not be used, because they may not have sufficient capacitive adjustment to preserve the waveshape of the observed signal. A sound rule is to use all test probes only with the equipment for which they were designed.

Voltage Checks

Voltage measurements are made at various points in the stage suspected of being at fault, and the observed voltage values are compared with the normal voltage values given in the Maintenance Instruction Manual.

When making voltage checks for comparison with a chart, be sure to use a voltmeter with the proper ohms-per-volt rating (sensitivity). Voltmeters are connected in shunt with the circuit elements under test, resulting in circuit loading. If the sensitivity of the test instrument is the same as that used in obtaining the readings given on the chart, the loading effect will be the same in both cases, and the readings obtained are reliable. Another important point to remember is that if the meter sensitivity is too low, loading effect may be so severe as to prevent proper operation of an otherwise normally functioning circuit.

From this comparison, the defect can often be isolated. Voltage checks are most effective when applied within a single stage, after previous checks have been made to localize the defect. This is true because modern electronic equipment is complex, and a great deal of time is required to check all the voltages present in all the stages.

Some electronic equipments have built-in meters or plugs for front panel application of meters. These meters usually work in conjunction with a selector switch, and will read values of voltage or current at designated points. A defective stage can often be located in this manner.

Once the defective stage is isolated, it becomes a matter of point-to-point checking to isolate the fault within the stage itself. A voltmeter will usually pinpoint the trouble area, but it often becomes necessary to use an ohmmeter to determine the exact cause of trouble, such as shorted capacitors, open resistors or transformers, or wire grounded to chassis.

Resistance Checks

Resistance checks are similar to voltage checks except that the power is removed from the equipment. Resistance values are measured with an ohmmeter, and the readings are compared with the normal values given in the maintenance publications. Resistance checking, like voltage measurement, is most effective after the trouble has been isolated to a particular stage. Reliance on resistance measurement alone is too time consuming to be efficient. After the trouble has been isolated, the ohmmeter is a very useful instrument and often quickly leads the technician to the cause of the trouble.

NOTE: In order to prevent damage to the ohmmeter, always be sure that there are no voltages present in the equipment prior to beginning the resistance checks. Turn off the power switches, discharge power supply and other large capacitors, and bleed off any other residual charges in the equipment. Also observe proper precautions when connecting or disconnecting the ohmmeter across large inductors.

A typical example of a routine resistance check applied to a single part is the ohmmeter method of checking electrolytic capacitors. A resistance measurement is made on the discharged capacitor, using the high resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should then rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

Do not leave the ohmmeter connected across an electrolytic capacitor for any appreciable period of time. Electrolytic capacitors are polarity-sensitive, and reverse polarity of voltage (even from an ohmmeter) may cause excessive current which could result in overheating and possible explosion of the capacitor.

If the capacitor is open, no deflection will be noted. If the capacitor is shorted, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that there is some current leakage between the electrodes. Because the electrolytic capacitor is a polarized device, the resistance is greater in one direction than in the other.

Should a capacitor indicate a short circuit, one end of it must be disconnected from the circuit and another resistance reading taken to determine if the capacitor is actually at fault.

Unless the ohmmeter has a very high resistance scale the deflection of the meter when checking small value capacitors will not be noticeable. Even a scale of R × 10,000 is not sufficient for very small capacitors; the smaller the capacity the less leakage across the plates, therefore the more resistance.

When making resistance checks, be sure to determine what circuits are connected to the points where the checks are made. The Maintenance Instruction Manual will indicate what resistance should be found at various checkpoints throughout the equipment and will contain a complete schematic of the set as well as a circuit schematic of the stage under test. The schematics may set up conditions under which voltage and resistance measurements are to be made, such as positions of switches, and control knobs, relays energized or deenergized, tube in socket, etc. These conditions will duplicate the conditions under which the measurements were first made. A typical condition might be: "Power switch OFF-all controls on the control box fully CCW (counterclockwise)." It is important that these instructions be followed to obtain accurate values to compare with specific values. Otherwise incorrect values may be obtained.

Defective Components

Before replacing a defective part it is necessary to determine if such an operation may be performed by the unit or squadron. This has been determined by the level of maintenance that has been assigned to your particular activity. Increasing complexity and compactness of electronic equipment have resulted in a trend toward replacement of subassemblies rather than individual parts. This trend is caused by the necessity of exact parts replacement, and the difficulty of working in small space, where even the amount of solder used on a connection can be of importance. However, there are many parts that may be replaced at any level of maintenance.

Should it become necessary to replace a part with a substitute, the technician must make sure that the substitute part is a proper replacement. With resistors, for instance, several characteristics must be considered—ohmic value, wattage rating, tolerance, physical size, and type of construction. Capacitors involve consideration of physical size, capacity, tolerance, temperature coefficient, and voltage rating. Plugs and connectors will almost invariably have to be exactly as prescribed since it is difficult to find items of this type that are interchangeable.

Publications may be consulted to aid in obtaining information (such as stock number and description) about a particular part. Familiarity with the IPB is a definite asset to the technician who must determine exactly what part to order.

Checking After Repair

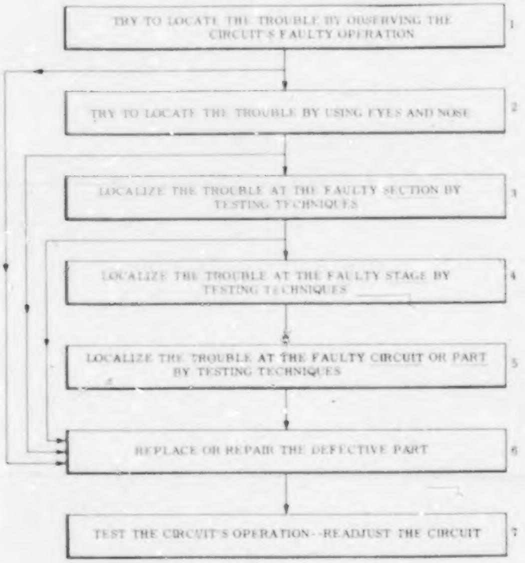
No repair job is complete until the repaired equipment is reinstalled and actually operating properly. The equipment must be bench checked after the trouble is remedied, usually before the equipment is completely reassembled, and any alinement adjustments necessary to assure proper operation should be made. After reassembly of the equipment-replacement of dust and shielding covers, installation of equipment in outer case (and pressurization if necessary)—a final bench operational check should be performed. Oftentimes a shield or plate that has been installed will touch a bare wire or other contact and will render the equipment inoperative, or cause substandard operation. It is much better to discover such a fault at the bench than in the aircraft.

After the equipment is reinstalled in the aircraft and properly secured for flight, it must be given a final operational test. It cannot be assumed that because the equipment operated properly on the bench it will do so in the aircraft. The most important test is an operational check under exact operating conditions. When the equipment performs properly in the aircraft and is securely mounted, the discrepancy may be signed off.

The troubleshooting information described in the preceding paragraphs is summarized in figure 6-2, which shows in chart form a general troubleshooting procedure. The directions given in blocks 1 through 5 are steps to be used in locating trouble, and the directions given in blocks 6 and 7 are steps in repairing the equipment. (Steps 2, 3, 4, and/or 5 may sometimes be eliminated, but steps 6 and 7 will always be followed.)

MAINTENANCE BY EXCEPTION

All maintenance is related to some form of management. The function of management has been defined as "the efficient attainment of enterprise objectives." Maintenance has also been defined as "all actions taken to retain material/equipment in a serviceable condition or to restore it to serviceability." When these are combined, we can define Maintenance Management


TRY TO LOCATE THE TROUBLE BY OBSERVING THE CIRCUIT'S FAULTY OPERATION
1
TRY TO LOCATE THE TROUBLE BY USING EYES AND NOSE
2
LOCALIZE THE TROUBLE AT THE FAULTY SECTION BY TESTING TECHNIQUES
3
LOCALIZE THE TROUBLE AT THE FAULTY STAGE BY TESTING TECHNIQUES
4
LOCALIZE THE TROUBLE AT THE FAULTY CIRCUIT OR PART BY TESTING TECHNIQUES
5
REPLACE OR REPAIR THE DEFECTIVE PART
6
TEST THE CIRCUIT'S OPERATION--READJUST THE CIRCUIT
7

AT. 261

Figure 6-2.—Troubleshooting procedure.

as "the actions necessary to retain/restore material/equipment in a serviceable condition with a minimum expenditure of resources." Resources are commonly referred to as men, money, and material.

Maintenance by exception is fundamental to this entire management system. It means simply that actions or incidents which vary markedly from established standards or norms are singled out as exceptions from the whole for special management attention. For example, if certain black boxes within a weapons system consistently fail to produce the desired results, then they would be singled out for special study and corrective action. Since the normal would be correct operation and these black boxes were chronically failing and consuming abnormal numbers of man-hours, they would be considered an exception.

REPAIR INFORMATION

As was mentioned previously, increasing complexity and compactness of electronic equipment have caused a trend toward replacement of subassemblies rather than individual parts. This trend is caused by the necessity of exact parts replacement, and the difficulty of working in small areas where even the amount of solder used can contribute toward trouble free operation. However, there are many parts that will need to be replaced, and the rule is to replace a defective part with an exact duplicate.

The trend toward replaceable units has led to several new methods of construction of electronic equipment. Two methods are MICROELECTRONICS and PRINTED CIRCUITS. These circuits are designed for speed and economy of manufacture, and speed and ease of maintenance, as well as saving of space and weight.

MICROELECTRONICS

The Naval Air Systems Command uses the term MICROELECTRONICS to refer to those processes and techniques involved in the construction of circuits in a relatively small, nonseparable form. Active elements such as transistors, and passive elements such as resistors and capacitors are closely integrated on a single wafer or block to form a functional circuit.

Microelectronics includes the construction technique referred to as integrated circuitry; it also includes the thin-film techniques; and, in some cases, it includes the use of discrete microcomponents (for example, a transistor made separately and then added to an assembled unit). The term is not used to include construction using miniature but otherwise conventional components with interconnecting wiring between the individual components, even though some wiring may be required between assemblies in microelectronic construction.

MICROMINIATURIZATION, on the other hand, is a term generally having a broader meaning. This term is used to refer to all efforts directed toward making electronic devices as small as possible. The Army's micromodular construction technique, for example, is excluded from the NavAir concept of microelectronics, although it represents a good example of microminiaturization. The micromodule consists of tiny wafers of insulating material, on each of which is mounted an electronic element such as a diode, capacitor, transistor or resistor. These elements, some the size of pinheads, are connected by wire threads. Micromodules represent the last practical step in the process of miniaturizing conventional electronic devices. Hundreds of thousands of such elements can be crammed into a cubic foot of space. Microelectronic devices are even smaller than micromodules.

PURPOSES OF MINIATURIZATION

In conventional circuits, electrical connections are the cause of numerous failures. As electronic systems become more complex, the increase in the number of parts used and of the connections between them decreases the potential reliability of the circuitry. A characteristic of microelectronic devices which is even more important than their small size is the drastic reduction in the number of soldered connections required. Using a single block of semiconductor material, it is possible to fabricate complete functional subassemblies which require only connections for inputs and outputs from the assembly.

The major objective of the microelectronics trend is to develop building blocks, with each block capable of performing the function of a complete circuit or group of circuits. With this capability, the block should then have one or more of the following characteristics:

1. Perform more electronic functions per unit of volume, weight, cost, power input, and power dissipated than is possible with even the most advanced components and circuit assembly techniques currently available.
2. Possess considerably higher reliability than their conventional counterparts.
3. Require a minimum of maintenance as a result of improved reliability.
4. Achieve low unit cost, making throwaway maintenance practices economically practicable.
5. Perform certain new functions which are not possible with presently available components.

Size reduction alone is not always the aim of microelectronics; small size is inherent in the technology. Although the size and weight reductions are highly significant, in some applications they do not justify the development of an entirely new system of fabrication.

Trouble isolation to a module rather than a specific component part reduces the number of items to be checked, and thus decreases maintenance time. The requirement of increased reliability at reduced cost is inherent in this form of maintenance. By mechanizing production and improving processing techniques, the initial cost can be drastically reduced; by automatic system checkout techniques, trouble isolation can be made almost completely automatic.

CLASSES OF COMPONENTS

The conventional circuit with normal or miniature components will continue to be used. Some components such as the magnetron and high power-consuming devices do not, at present, lend themselves to drastic size reduction. Miniature components, although they do not compare with thin-film or solidstate integrated circuitry in size reduction, will also continue to be used in military applications. Unfortunately, only a limited selection of miniature components, modules, and packaged assemblies is available. It is estimated that 25 to 30 percent of all military needs for electronic circuits will continue to be filled for years to come by normal or miniature components.

This discussion describes the various classes of microminiature components now being used, reviews a few of the present applications, and notes some of the problems yet to be solved in the microelectronic techniques.

Discrete Components

In reducing weight and bulk, the microminiature component goes one step farther than the miniature component. Capacitors, resistors, transistors, and diodes are currently being used in conjunction with passive thin fiims. By micropackaging techniques, size and weight reduction is realized, but the connection into usable circuits is a time-consuming and tedious operation, and the soldered connections do not realize full reliability potential.

Hybrid Circuits

Hybrid circuits using thin-film subassemblies of passive elements to which the active elements are attached represent the next logical step in fabrication. The number of soldered connections is reduced and the number of wafers is also decreased. Thus, this method is a slightly improved example of microminiaturization which is sometimes included in the definition of microelectronics.

Thin-Film Devices

Thin-film microelectronic devices consist of passive elements (currently limited to resistors, capacitors, and small inductors) on substrates of glass, ceramic, steatite, or other suitable insulating material. All active elements, and some passive elements, are added to the circuit as discrete components.

Solidstate Integrated Circuits

Solidstate integrated circuits represent an extension of silicon transistor technology. These circuits derive their name from the fact that the circuit is formed in a single block of silicon semiconductor material. They contain both active and passive circuit elements interconnected with deposited metal patterns. The selection of circuits fabricated on the solidstate principle is at present the limiting factor in utilization of the solidstate module. Considerable development emphasis is being given to this limiting factor.

TECHNIQUES

There is a difference between microelectronics and micropackaging. The latter generally refers to the assembly of discrete, miniaturized components within a single enclosure and electrically connected by wires and deposited films. This technique is similar to conventional methods in that separate, discrete components are used. The individual component cases or enclosures may, however, be removed and the individual components bonded to a common substrate and interconnected, with the complete subassembly then hermetically sealed in a single package. The individual components must be individually processed, handled, and interconnected. This decreases the reliability of the assembly, and increases the unit cost. It does, however, approach the size and weight reduction of microelectronic circuits.

In true microelectronic technology, all the equivalent components (active and passive) are fabricated in one continuous operation on an entire block of material. The components never need to be handled as individual items, and all connections except input to and output from the circuit are an integral part of the block. This technique maximizes reliability because of the lack of separate interconnections within the individual module. Computer-controlled automatic processing techniques will standardize construction and reduce unit cost of producing the modules, making throwaway maintenance economically practicable.

Actual production and manufacturing techniques presently in use are summarized briefly in the following paragraphs.

Deposited Film Technique

This technique involves the fabrication of circuits which are composed of thin films of metallic or semiconductor material deposited on substrates. The individual elements of these circuits cannot be disconnected from each other.

Several methods are used to deposit the film. The most commonly used method consists of evaporating a metallic or dielectric material in a high vacuum and condensing the vapor onto a thin inactive wafer. Carefully prepared masks control the areas exposed for deposition. By successive steps of depositing metallic or dielectric films, resistors, capacitors, and conductors can be deposited onto a single wafer. (Note that reference is made to the conventional types of components as used in the part. The differences are that there are no leads between components, and that circuit interconnections are an inherent part of the process.)

Other methods used to deposit the film include the oxidation of certain metals, thermal decomposition of gaseous compounds, and "sputtering." In the oxidation process, the metal is first deposited onto the substrate, and a specified section is then oxidized to obtain special characteristics. In thermal decomposition, extremely close tolerances are required in the masking, purity of the compound, temperature, and exposure time.

Some materials have extremely high melting temperatures and are therefore almost impossible to deposit by the evaporation technique. For these materials, the sputtering technique has been developed. In this process, the material is boiled under extreme heat in a high vacuum, and then deposited in small droplets onto the substrate wafer.

Silk Screen Technique

In this process, a mixture of special sand and fluxes is applied to a ceramic substrate and then the unit is fired (in a manner similar to the ceramic painting and glazing process). Prior to firing, interconnections are screened on, using metallic "inks"; external connections are welded, brazed, wire-bonded, or soldered after firing. Use of the silk screen technique results in a film of considerably greater thickness than that of the thin-film technique.

Semiconductor Growth

This technique is the one most commonly used in the production of solidstate circuits. The process begins with a single bulk-form block of semiconductor material as the substrate. Impurities are alloyed or diffused into the material to form PN junctions. (The semiconductor material itself is used in the formation of resistors and capacitors.)

In most cases the elements themselves and their interconnections are integral parts of the semiconductor substrate; differentiation between the elements and the substrate becomes vague. Internal interconnections are reduced by designing one element to begin where another ends.

MANUFACTURING PROCESS.—The manufacturing process consists of a number of steps using silicon dioxide masks to control the doping of the semiconductor material. By use of computer-controlled equipment, the original block of semiconductor material is progressively masked, doped, oxidized, etched, and otherwise processed to form junctions which possess the desired characteristics. Thus, a single block of material may contain the equivalent of various combinations of transistors, diodes, resistors, capacitors, and interconnecting wires, with areas provided for connecting leads for input signals, power, and output signals.

CHARACTERISTICS.—The performance of solidstate circuits is limited by the capacitance of the back-biased junctions between the silicon substrate and the N-type islands in which the circuit elements are diffused. This parasitic capacitance has been a limiting factor in obtaining good high frequency response.

Resistance and capacitance values are somewhat more limited in solidstate circuits than they are in thin-film networks, and inductance is as yet unattainable. Circuit resistor tolerances of closer than 20 percent are difficult to attain. Temperature coefficients are relatively large for all components. Capacitors have low values of Q, are polarity-restrictive, and have comparatively low voltage breakdown values.

The absence of interconnections in completely integrated circuits should lead to greatly improved reliability, simplified maintenance practices, and shorter "downtime" losses.

Power capabilities are limited by the drift in circuit characteristics caused by internally generated heat. Power dissipation is therefore greatly restricted.

APPLICATIONS

Microminiaturized and microelectronic circuits and components are appearing in virtually all new equipments. It is expected that microcomponents and microcircuits will eventually replace about 75 percent of those in present use. However, there are some specific applications especially well suited for their usage.

Equipments involved in automatic data processing, logical computations, sequential switching, or precise navigation are currently being designed as integral parts of an overall weapon system—and they are being designed with microcircuit techniques. Another area particularly well suited for miniature and microcircuits is the survival transceiver packed in the liferaft of ejection seats.

MICROMAINTENANCE

Microelectronic technology by itself will not solve the maintenance problem. In spite of the greatly increased reliability, failures will still occur. When they do, the faulty items must be isolated and repaired or replaced.

With the discrete miniature component (transistor, resistor, capacitor, etc.), the maintenance technician can test individual circuit elements and thus determine the cause of failure. Repairs can then be made by replacing the faulty component.

With the integrated circuit, replacement of an individual part is impossible because the unit is designed and exists only as a complete functional element. The maintenance process then becomes a matter of isolation and replacement of the defective "chip," "flat-pack," board, or module.

Modules

Modular assemblies are mechanically more rugged than conventional circuits. They are, however, susceptible to damage from improper handling, electrical overload, or overheating. Techniques of maintenance and servicing are similar to those used with conventional circuits, but require somewhat more care in execution.

The small size and close spacing of the parts within the assembly require more care and smaller tools than are normally required in conventional maintenance. Additional devices and maintenance aids are of great help in developing the precision needed for such close work. Many components are inherently susceptible to damage from various causes. These factors require modification of some of the basic maintenance techniques and the use of some new ones.

Component damage during maintenance is usually the result of excess heat during repair, reversed polarity of ohmmeters while checking for continuity, application of excessive voltages or signal magnitudes during testing, rough handling, or use of the wrong tools or materials.

Loosening connections, disconnecting parts, inserting or removing transistors, and changing modular units should not be done with the power on or while the circuit is under test. These actions (or a loose connection of any type) will cause an inductive kickback, which may damage the component.

It is also important to remove any capacitive charge from parts, tools, or test equipment before connecting them to any modular unit. A grounding clip should be connected from the item to the modular chassis before making any other contact. When disconnecting, the grounding clip should be removed last.

Leads to transistors, printed circuit boards, etc., as well as many miniature components are easily damaged in handling, stowage, or shipping. Proper precautions should be used at all times.

It should be emphasized that these miniature components and circuits can be repaired, if adequate care and proper techniques are used.

BOOK CIRCUITS

Figure 6-3 shows an improved type of construction, from the troubleshooter's standpoint, consisting of a removable subassembly of the type called "books." These books are readily removable and have numerous internal and external test points to facilitate troubleshooting. The books are built of easily replaceable standard parts. Most test racks have plug extensions that permit any book to be raised, making all parts accessible for checking and repairing. The book is not expendable, but can be easily repaired since all parts are of conventional design. Miniature and subminiature parts are so common in today's electronic equipment that they are now considered to be conventional.

PRINTED CIRCUITS

Although maintenance procedures for printed circuits are similar to those for other circuits, they require more skill and care. Any defective part should be pinpointed by careful analysis of the symptoms before attempting to trace trouble on a printed circuit board.

Breaks in the conducting foil strip can cause either permanent or intermittent trouble. When searching for a break in the foil, first determine whether the strips have a protective coating. If so, it will be necessary to penetrate this film when checking for continuity. A needlepoint probe works nicely.

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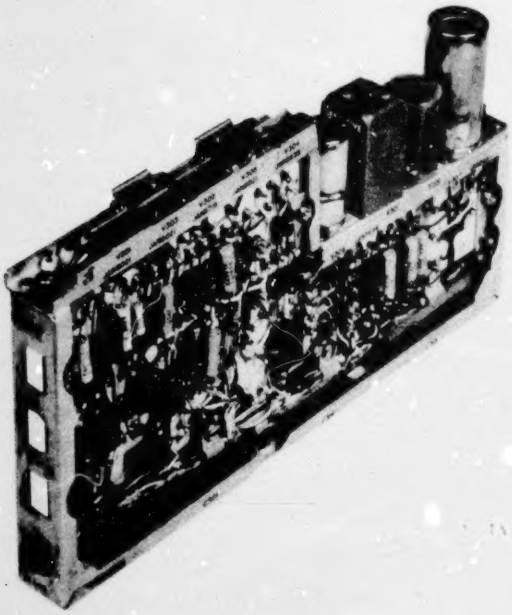
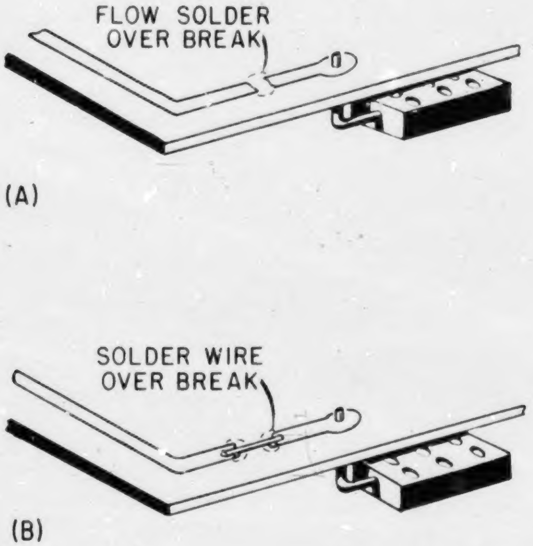


AT. 146

Figure 6-3.—Electronic "book" construction.



AT. 266

Figure 6-4.—Repairing breaks in foil.

Use a multimeter or an ohmmeter for checking continuity. Use a meter that passes no more than one milliampere. If the circuit contains transistors or other semiconductors, observe proper biasing conditions.

First check for continuity from one end to the other of each strip (being sure to penetrate the protective coating, but being careful not to damage the strip). If an open is indicated, move the probes one at a time until continuity is indicated. The break then lies between the last two positions of that probe. Carefully inspect the break to determine its extent and the repair process needed.

If the break is small, carefully scrape away any protective coating, clean the area with a firm bristle brush and an approved solvent, and flow solder over the break as indicated in figure 6-4(A). If there is any indication that the strip might peel loose from the board, bridge the break with a small section of bare wire as indicated in figure 6-4(B). Apply solder along the entire length of the wire to bond it firmly to the conducting strip. Keep the solder within the limits of the strip being repaired, to prevent the solder from flowing onto or near an adjacent strip. Be careful not to overheat any part of the area.

If a strip is burned out or fused, cut and remove the damaged strip and replace it with a wire soldered from terminal to terminal on the board.

A printed circuit board can withstand only a limited amount of flexing. Excessive flexing results in a broken board, which must then be replaced. When working on a board which is still mounted in its normal location, never use pressure.

After repairs are completed, thoroughly clean the board, restore the protective coating, and allow to dry thoroughly before reinstalling or applying power to the circuit.

Removal of transistors, tube sockets, or other parts from a printed circuit board often requires the simultaneous movement of several soldered connections. For this purpose use the pencil type soldering iron and special tips when possible. Remove excess solder from each connection, using a scribe or needle probe to scrape away the solder. Do not rock or pry the part to loosen the connection—rocking may damage the board. When all connections are free, simply lift the part.

To install the replacement part, solder each connection separately, in turn.

SEMICONDUCTORS

Transistors, unlike vacuum tubes, are very rugged in that they can tolerate vibration and a rather large degree of shock. Under normal operating conditions they will give dependable service over a long period of time. However, transistors are subject to failure when subjected to even minor overloads. Crystal detectors are also subject to failure or deterioration when subjected to electrical overloads; in addition they will deteriorate from long periods of normal use.

In order to determine the condition of semiconductors, various test methods can be used. In many cases it is possible to substitute a transistor known to be good for a questionable one; and thus determine the condition of a suspected transistor. This method of test is highly accurate and sometimes expeditious. However, indiscriminate substitution of semiconductors in critical circuits is to be avoided. When transistors are soldered into equipment, substitution becomes impracticable; it is generally desirable to test these transistors in their circuits.

Since general fundamental characteristics are an indication of the condition of semiconductors, test equipment is available for determining these characteristics with the semiconductor both in and out of their circuits. Crystal-rectifier testers normally test only the forward and reverse current ratio of the crystal. Transistor testers are capable of measuring several characteristics, such as the leakage current (I_{co}), the current gain (beta), and the four-terminal network parameters. The most useful characteristic for test purposes is determined by the type of circuit in which the transistor will be used. The beta measurement is preferred for a-c amplifiers or oscillator applications. For switching-circuit applications, a direct-current measurement may be more useful.

Semiconductor Designation

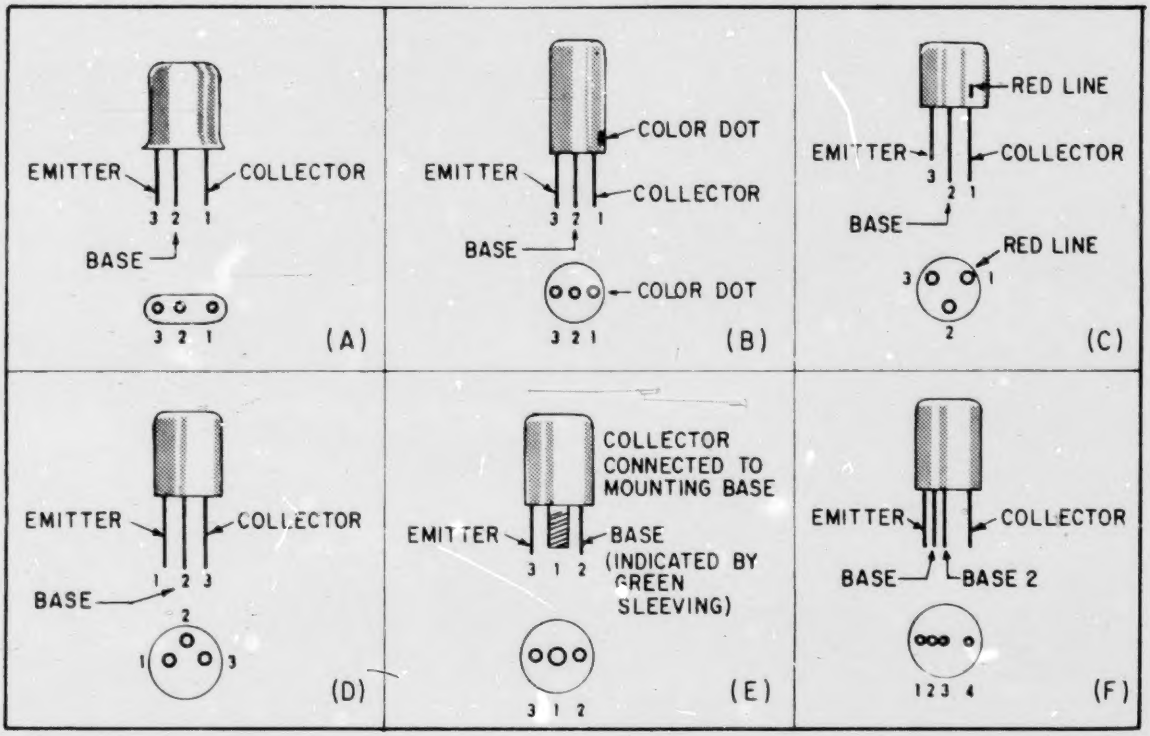
Semiconductors are designated by the use of number and letter combinations that have been accepted as standard. The first number indicates the number of junctions and the letter "N" indicates a semiconductor. The number following the letter indicates the registration order. An example is the 1N21B. The "1" preceding the "N" indicates a diode. The "N" indicates a semiconductor. The 21B indicates the 21st registration and the "B" indicates a modification of a 1N21A semiconductor.

Transistors also are identified by the number-letter-number sequence, that is, a 2N130 would be a triode transistor, registration number 130. Even though the above information is considered to be standard, different manufacturers will sometimes use their own numbering system.

Semiconductor Basing and Basing Diagrams

Diodes have only two leads and a dot or color indicates the cathode terminal. Transistor leads generally have a color dot to indicate the collector lead or the collector is spaced farther from the other leads. The lead farthest from the collector, in line, is usually the emitter and the base lead is between the collector and emitter leads. This is shown in figure 6-5(A). When the leads are evenly spaced, a red dot indicates the collector, as shown in figure 6-5(B). If the base is circular, a red line indicates the collector and the emitter lead is the shortest lead. This is shown in figure 6-5(C). In figure 6-5(D), the triangular arrangement is off-set and the lead opposite the blank quadrant is the base lead. The collector is the first lead clockwise from the base. In power transistors, the collector lead is usually connected to the mounting base and the emitter lead will be identified by a color, as shown in figure 6-5(E). One method of identifying leads of tetrode type transistors is shown in figure 6-5(F).

Whenever a doubt exists regarding a particular type of semiconductor, a transistor manual or manufacturer's specification sheet should always be consulted.


EMITTER
COLLECTOR
3 2 1
BASE
3 2 1
(A)
COLOR DOT
EMITTER
COLLECTOR
3 2 1
BASE
COLOR DOT
3 2 1
(B)
RED LINE
EMITTER
COLLECTOR
3
2 1
BASE
RED LINE
3 1
2
(C)
EMITTER
COLLECTOR
1 2 3
BASE
2
1 3
(D)
COLLECTOR CONNECTED TO MOUNTING BASE
EMITTER
BASE (INDICATED BY GREEN SLEEVING)
3 1 2
3 1 2
(E)
EMITTER
COLLECTOR
BASE
BASE 2
1 2 3 4
(F)

AT. 267

Figure 6-5.—Transistor lead identification.

SEMICONDUCTOR MEASUREMENTS

Because of the reliability of semiconductor devices, servicing techniques developed for transistorized equipment differ from those normally used for vacuum tube circuits. Vacuum tubes are usually considered to be the circuit component most susceptible to failure, and are therefore normally the first components to be tested. Transistors are capable of operating in excess of 30,000 hours at maximum rating without appreciable degradation, and are often soldered into the equipment in the same manner as resistors and capacitors.

Substitution Test

Substitution of a crystal diode or transistor, known to be in good condition, is one method of determining the quality of a questionable semiconductor device. This technique should be used only after voltage and resistance measurements are made to insure that there is no circuit defect that might damage the substituted semiconductor device. If more than one defective semiconductor is present in the equipment section where trouble has been localized, this method becomes cumbersome, since several semiconductors may have to be replaced before the trouble is corrected. To determine which stage failed and which semiconductors are not defective, all of the removed semiconductors must be tested. This can be accomplished by observing whether the equipment operates correctly as each of the removed semiconductor devices is reinserted into the equipment.

TRANSISTOR MEASUREMENTS

When trouble occurs in transistorized equipment, power supply voltage measurement, waveform checks, signal substitution or tracing methods are normally the first tests made. If a faulty stage is isolated by one of these test methods, voltage, resistance, and current measurements can be made to locate the defective part. When making these measurements care must be taken to make certain that the voltmeter resistance is high enough to have no appreciable effect upon the voltage being measured, and that the current from the ohmmeter will not damage the transistor. If the transistors are not soldered into the equipment, it is usually advisable to remove the transistors from their sockets during resistance tests. Transistors should be removed from or reinserted into their sockets only after power has been removed from the stage, since damage by surge current may result.

Transistor circuits other than pulse and power amplifier stages are usually biased so that the emitter current is in the vicinity of 0.5 to 3 milliamperes and the collector voltage is 3 to 15 volts. The emitter current can be measured by opening the emitter connector and inserting a milliammeter. When making this measurement, some change in bias should be expected due to the meter resistance. The collector current can often be determined by measuring the voltage drop across a resistor in the collector circuit and calculating the current by ohms law. If the transistor itself is suspected, it can be tested by the method described previously.

Resistance Test

An ohmmeter can be used to test transistors by measuring the emitter-collector, base-emitter, and base-collector forward and back resistances. Check the ohmmeter handbook to determine the polarity of the test leads. Some models apply reverse voltage from the internal battery.

CAUTION: Any ohmmeter used which is capable of delivering current in excess of 1 milliampere may damage the transistor. USE ONLY AN APPROVED TYPE OHMMETER.

A back-to-forward resistance ratio on the order of 500 to 1 should be obtained for the collector-to-base and emitter-to-base measurements. The forward and back resistances between the emitter and collector should be nearly equal. All three measurements should be made for each transistor tested, since experience has shown that transistors can develop shorts between the collector and emitter and still have good forward and back resistance for the other two measurements.

Because of shunting resistances in transistor circuits, it will normally be necessary to disconnect at least two transistor leads from the associated circuit for this test. Caution must be exercised during this test to make certain that current during the forward resistance tests does not exceed the rating of the transistor.

HANDLING TRANSISTORS

Transistors, although generally more rugged mechanically than vacuum tubes, are susceptible to damage by excessive heat and electrical overload. The following precautions should be taken in servicing transistorized equipment:

1. Test equipment and soldering irons must be checked to insure that there is no leakage current from the power source. If leakage current is detected isolation transformers must be used.
2. Ohmmeter ranges which require a current of more than 1 milliampere in the test circuit should not be used for testing transistors.
3. Battery eliminators should not be used to furnish power for transistor equipment because they have poor voltage regulation and, possibly, high ripple voltage.
4. The heat applied to a transistor, when soldered connections are required, should be kept to a minimum by using a low-wattage soldering iron and heat shunts, such as long-nose pliers, on the transistor leads between the soldering iron and the transistor.
5. All circuits should be checked for defects before a transistor is replaced.
6. The power should be removed from the equipment before replacing a transistor or other circuit part.
7. When working on equipment with closely spaced parts, conventional test probes are often the cause of accidental short circuits between adjacent terminals. Momentary short circuits, which rarely damage a vacuum tube, may ruin a

transistor. To avoid accidental shorts the test probes can be covered with insulation for all but a very short length of the tips.

SERVICING SEMICONDUCTOR CIRCUITS

Most new circuit design is based on the use of semiconductors. While some devices operate safely at high temperatures, the majority of transistors and crystal diodes in present use are particularly sensitive to temperature.

When transistors are mounted in sockets, they should be removed from the sockets before any soldering operations on the terminals are begun. Some transistors and most crystal diodes in printed circuits, however, are soldered in place. All connections must be desoldered before the semiconductor can be removed. Semiconductors cannot safely withstand the heat produced even with the pencil soldering iron. It is necessary, therefore, to use a heat shunt.

The soldering gun should not be used to solder or desolder semiconductor components in equipment. The strong electromagnetic field produced by the gun may cause induced currents great enough to damage the component.

Even conventional irons should be grounded to the chassis of transistorized equipment under repair, as mentioned previously, to prevent damage from accumulated electrical charges.

Semiconductors and many other miniature components are extremely susceptible to damage from electrical overloads. The maximum ratings for components are usually given in the technical manuals and in the charts and tables supplied for each equipment or major component. These ratings should not be exceeded.

Transistors and similar components require various power supply connections. When preparing a unit for operation on the test bench or in a breadboard type hookup, check the voltages and their polarities against the tables and drawings before activating the power. When using an ohmmeter for continuity testing, check the range and short circuit current rating of the meter before attaching it to the transistor.

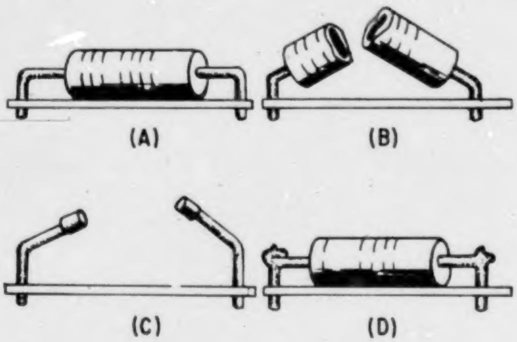
Reversing the plate voltage on a triode vacuum tube will generally keep the tube from operating, but will normally not damage the tube. Semiconductors, however, are polarity-sensitive. Reversing the collector voltage polarity of a transistor or other semiconductor may ruin it instantly and permanently.

Leakage current from test equipment to the modular unit can also destroy transistors and other semiconductors. To prevent this, the use of an insolation transformer is recommended for those test sets which do not operate with transformer supplies to produce their operating voltages. In any event, the use of a grounding strap is recommended for all test equipments and instruments used in servicing or testing these circuits. The ground should be connected first to the module chassis, then to the test equipment ground post or chassis.

High magnitude pulses will also destroy transistors. Test equipment should be connected with minimum output or maximum attenuation settings, and gradually adjusted to the desired level.

TERMINAL BOARDS

It is often possible to replace a defective resistor or capacitor without removing the board from the chassis. If the leads extending from the defective component are long enough for a replacement part to be soldered to them, they may be cut where they enter the defective component. If the leads are not long enough, it is possible to get extra length by the method shown in figure 6-6. Cut the part in half and



AT. 268

Figure 6-6.—Replacing resistor.

crush each half to take advantage of the lead length within the part. Make a hook in the remaining length of lead, then connect the new part.

When any soldering operation is necessary, use the pencil iron and its special tips with a ground lead connected from the tip of the soldering iron to the chassis of the part. Usually it is more convenient, and it is always safer, to completely remove the terminal board and work on an insulated surface, using a jig.

Any part to be removed should never be pried or forced loose. Any attempt to force a part loose may result in a broken or separated printed circuit panel. If the terminals do not pass easily through their holes, chances are that all the solder has not been removed. If any solder is left in the terminal hole after removing the leads, apply the soldering iron to the hole just long enough to soften the solder, and then gently poke the softened solder out with a toothpick, scribe, or small brush; or if necessary use a pin vise and drill.

RESISTORS

When a resistor must be replaced, one of the important considerations in selecting the replacement is the wattage value. In general, the wattage rating is a measure of the ability of the resistor to dissipate heat, and the value is related to the physical size of the resistor.

The selection of a safe wattage value is based on a consideration of the working conditions of the resistor in the circuit. Consider as an example the replacement of an 850-ohm resistor with one of equal ohmic value but which has a tolerance of ± 20 percent. Suppose the normal voltage existing across the resistor is 40 volts. Because of the 20 percent tolerance, the actual resistance of the replacement may be as much as 1,020 ohms or as little as 680 ohms. Taking the lesser value (the more unfavorable from a heat-dissipating standpoint), the power that may be developed in the resistor under circuit conditions is found as follows:

$$W = \frac{E^2}{R}$$

$$W = \frac{40 \times 40}{680}$$

$$W = 2.35 \text{ watts, approximately}$$

A resistor should be capable of dissipating from 1.5 to 2 times the power actually encountered, to allow sufficient margin of safety. In the example, this value is not more than 4.7 watts. Since a 5-watt resistor is the next standard size above the 4.7-watt value, this is a desirable wattage rating for the replacement.

Under emergency conditions, it is sometimes necessary to combine resistors in series or in parallel to obtain a desired resistance value. When this is done, care should be taken to avoid a voltage distribution (or current distribution) which causes any low-wattage resistor in the combination to dissipate an excessive amount of heat. For example, suppose two 10-watt resistors of 1-ohm value were combined in series with a 2-watt resistor of 10 ohms. The total wattage dissipated when the series combination is connected across 12 volts is 12 watts. But the power dissipated by the 10-ohm, 2-watt resistor is 10 watts, a value far in excess of its capabilities. It is necessary to consider each resistor in the combination and select a wattage value based on the voltage developed across the individual unit.

Cable Splicing

A cable splice, other than one made with the crimp-on splice or connector, is employed as an emergency measure only. Solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as possible.

Insulating Sleeving

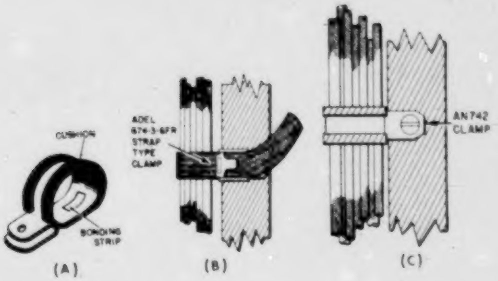
Insulating sleeving (commonly called "spaghetti") is used in electronic maintenance operations in many aviation activities. Among the operations involving use of the sleeving are the fabrication of cable connectors, connection to relays and terminal strips, crimped or soldered terminal lugs or splices, tie points on terminal strips or terminal boards, etc.

Support Clamps

Clamps are used to provide support for open wiring, and to serve instead of (or in addition to) lacing on open wiring. They are usually supplied with a rubber cushion. When used with shielded conduit, the clamps are of the bonded type (fig. 6-7(A)); that is, provision is made for electrical contact between the clamp and conduit. Unbonded clips are used for the support of open wiring.

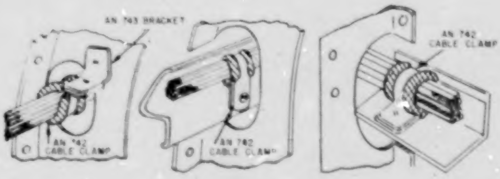
Long runs of cable between panels are supported either by a strap type clamp, shown in (B) of figure 6-7, or by a clamp of the type shown in (C) of the same figure. The preferred method of supporting cables for all types of runs is with the type shown in (C). When the strap type clamps are used, precautions must be exercised to insure that they will hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the aircraft; these clamps should be used only as an emergency measure.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 6-8. The cable should be routed clear of the edges of the lightening hole, to avoid any possibility of chafing of the insulation.



AE. 69

Figure 6-7.—Cable clamps.



AE. 70

Figure 6-8.—Routing cables through lightening holes.

Lacing and Tying

Wire groups and bundles are laced or tied to provide ease of installation, maintenance, and inspection. The purpose of lacing or tying is to keep all cables neatly secured in groups and thus avoid possible damage from chafing against equipment or interference with equipment operation.

TYING is the securing together of a group or bundle of wires by means of individual pieces of cord tied around the group or bundle at regular intervals. LACING is the securing together of a group or bundle of wires inside enclosures by means of a continuous piece of cord forming loops at regular intervals around the group or bundle.

A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.

Cotton, nylon, or Fiberglas cord is used for tying or lacing. The cotton cord must be waxed to make it moisture and fungus resisting. Nylon and Fiberglas cords are in themselves moisture and fungus resisting and are not usually waxed. Pressure sensitive vinyl electrical tape is used only where the use of tape instead of cord is specifically permitted.

When lacing or tying (fig. 6-9 and 6-10), observe the following precautions:

1. Lace or tie bundles tight enough to prevent slipping, but not so tight that the cord cuts into or deforms the insulation.

NOTE: Coaxial cables have been damaged by the use of lacing materials or by methods of lacing or tying wire bundles which cause a concentrated force on the cable insulation. Elastic lacing materials, small diameter lacing cord, and excessive tightening deform the interconductor insulation and result in short circuits or impedance changes.

2. Do not place ties on that part of a wire group or bundle that is located inside a conduit.
3. Lace wire groups or bundles only when they are inside enclosures, such as junction boxes. Use double cord on groups or bundles larger than 1 inch in diameter. Use single or double cord for groups or bundles 1 inch or less in diameter.

In some instances groups or bundles may be secured with tape. (See fig. 6-10(B).) The following method should be employed:

1. Wrap tape around wire group or bundle three times, with a two-thirds overlap for each turn.
2. Heat-seal the loose tape end with the side of a soldering iron heating element.

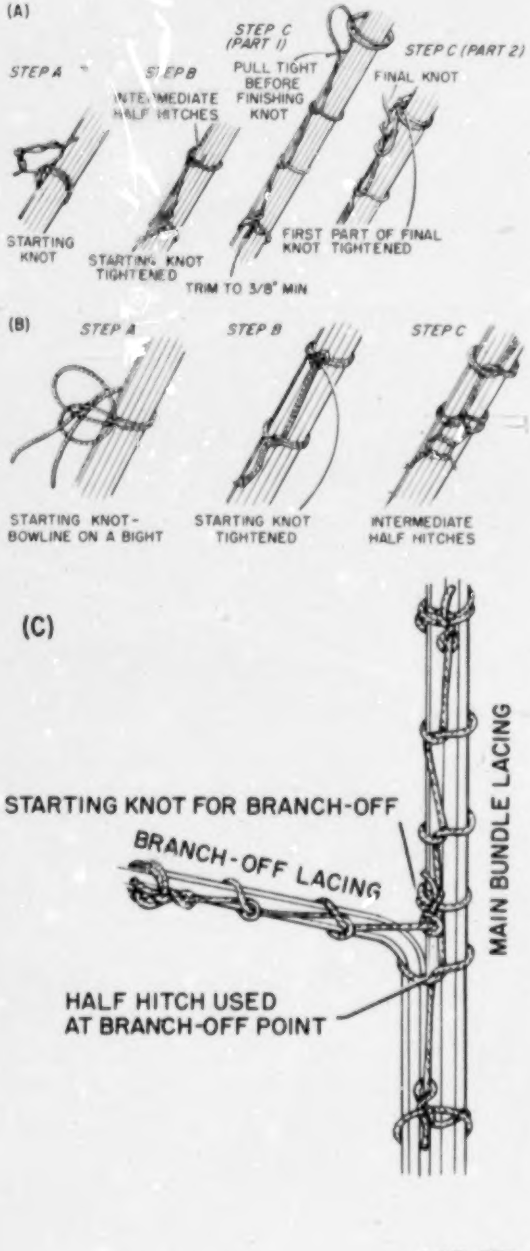
Do not use tape for securing wire groups or bundles which may require frequent maintenance.

BONDING

A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such a union results from either physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process of obtaining the necessary electrical conductivity between the component metallic parts of the aircraft. An isolated conducting part of an object is one that is physically separated by intervening insulation from the aircraft structure and from other conductors which are bonded to the structure.

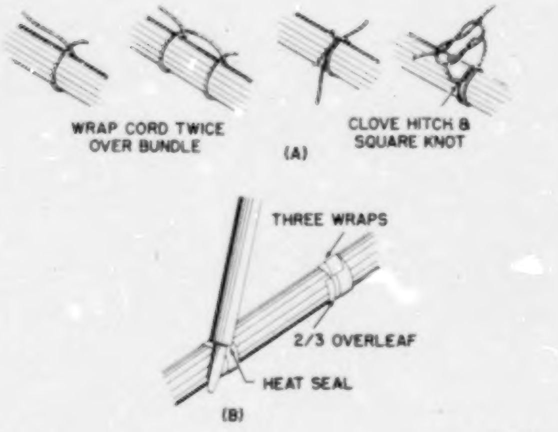
A bonding connector provides the necessary electrical conductivity between metallic parts in an aircraft not in sufficient electrical contact. Examples of bonding connectors are bonding jumpers and bonding clamps. (See fig. 6-11.)

An aircraft can become highly charged with static electricity while in flight. If the aircraft is improperly bonded, all metal parts will not have


(A)
STEP A
STEP B
STEP C (PART 1)
STEP C (PART 2)
PULL TIGHT BEFORE FINISHING KNOT
FINAL KNOT
INTERMEDIATE HALF HITCHES
STARTING KNOT
STARTING KNOT TIGHTENED
TRIM TO 3/8" MIN
FIRST PART OF FINAL KNOT TIGHTENED
(B)
STEP A
STEP B
STEP C
STARTING KNOT-BOWLINE ON A BIGHT
STARTING KNOT TIGHTENED
INTERMEDIATE HALF HITCHES
(C)
STARTING KNOT FOR BRANCH-OFF
BRANCH-OFF LACING
HALF HITCH USED AT BRANCH-OFF POINT
MAIN BUNDLE LACING

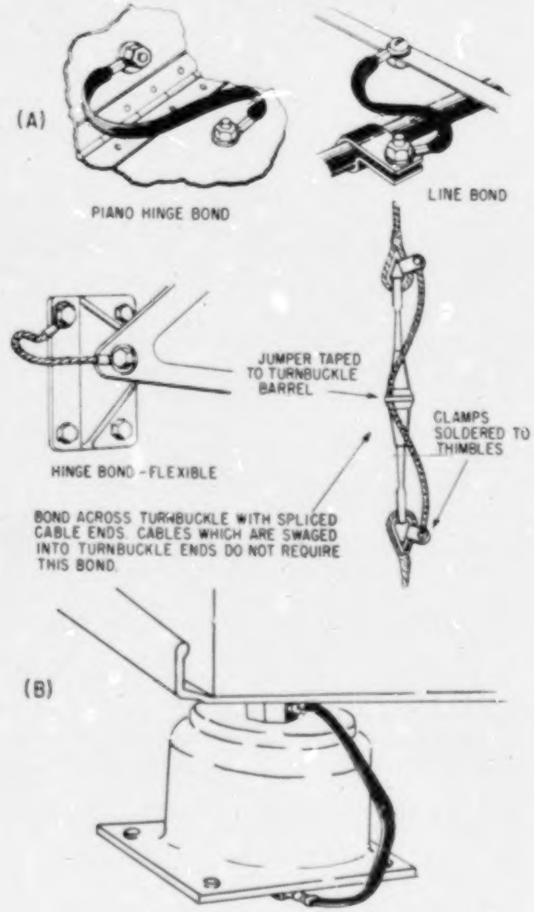
AT. 270

Figure 6-9.—Lacing wire groups or bundles.


WRAP CORD TWICE OVER BUNDLE
(A)
CLOVE HITCH & SQUARE KNOT
THREE WRAPS
2/3 OVERLEAF
HEAT SEAL
(B)

AT. 271

Figure 6-10.–Tying wire groups or bundles.


(A)
PIANO HINGE BOND
LINE BOND
JUMPER TAPED TO TURNBUCKLE BARREL
CLAMPS SOLDERED TO THIMBLES
HINGE BOND-FLEXIBLE
BOND ACROSS TURNBUCKLE WITH SPLICED CABLE ENDS. CABLES WHICH ARE SWAGED INTO TURNBUCKLE ENDS DO NOT REQUIRE THIS BOND.
(B)

AT. 272

Figure 6-11.–Bonding methods.

the same amount of charge. A difference of potential will then exist between various metal surfaces. The neutralization of the charges flowing in paths of variable resistance, due to such causes as intermittent contact from vibration or the movement of the control surface, will produce electrical disturbances (noise) in electronic equipment. If the resistance between isolated metal surfaces is great enough, charges can accumulate until the potential difference becomes sufficiently high to cause a spark. In addition to creating interference, this also constitutes a fire hazard. In the case of lightning striking the aircraft, a good conducting path is necessary for the heavy current in order to minimize severe arcs and sparks which would damage the aircraft and possibly injure its occupants.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance path also aids the effectiveness of the shielding, and provides a means of bringing the entire aircraft to the earth potential when it is grounded.

The reason for bonding may be summed up as follows:

1. To minimize radio and radar interferences by equalizing static charges that accumulate.
2. To eliminate a fire hazard by preventing static charges from accumulating between two isolated members and creating a spark.
3. To minimize lightning damage to the aircraft and its occupants.
4. To provide the proper ground for electronic and electrical equipment.
5. To provide a low-resistance return path for single-wire electrical systems.
6. To aid in the effectiveness of the shielding.
7. To provide a means of bringing the entire aircraft to the earth's potential and keeping it that way while it is grounded to the earth.

Bonding connection should be installed so that vibration, expansion or contraction, or relative movement incident to normal service use will not break the bonding connections or loosen them to such an extent that the resistance will vary during the movement. The bonding of most concern will be the bonding jumpers that are placed across shock mounts, used to support electronic equipment.

Since a primary objective for bonding is to provide an electrical path of low d-c resistance and low RF impedance, it is important that the jumper be a good conductor of ample size for the current-carrying capacity, have low resistance, and be as short as possible. Insofar as practical, parts should be bonded directly to the basic aircraft structure rather than through other bonded parts. Bonding jumpers should be installed in a manner so as not to interfere in any way with the operation of movable components of the aircraft.

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action) which causes a pitting in one of the metals. The intensity of this electric action varies with the different types of metals. Bonding frequently necessitates the direct contact of dissimilar metals. In such cases the metals used are of the kind that will produce a minimum of corrosion. The connections are also made so that if corrosion does occur, it will be in replaceable elements, such as jumpers, washers, or separators, rather than in the bonded or bonding members. Thus, washers made of the same material as the structural member should be used against the structural member, and washers of the same material as the bonded member should be in contact with that item.

Self-tapping screws should not be used for bonding purposes nor should jumpers be compression-fastened through plywood or other nonmetallic material. When performing a bonding operation, the contact surfaces should be cleaned of insulating finishes or surface films before assembly, and then the completed assembly refinished with a suitable protective finish.

SHOCK MOUNTS

Electronic equipment is sensitive to mechanical shock and vibration; therefore, units of electronic equipment are normally shock mounted to provide some protection against in-flight vibration and against launching and landing shock. The specific type shock mount is prescribed in the Maintenance Instructions Manual for the specific aircraft, and substitution should not be made.

Periodic inspection of shock mounts is required, and defective mounts should be replaced with the prescribed type. In the inspection, the main factors are deterioration of the shock absorbing material, stiffness and resiliency of the material, and overall rigidity of the mount. If the mount is too stiff or too rigid, it may not provide adequate protection against the shock of launching and landing; if it is not stiff or rigid enough, it may permit prolonged vibration following an initial shock. When determining the limits of rigidity and resiliency, consideration must be given to the weight of the mounted unit as well as the amounts of positive and negative acceleration to which it is subjected.

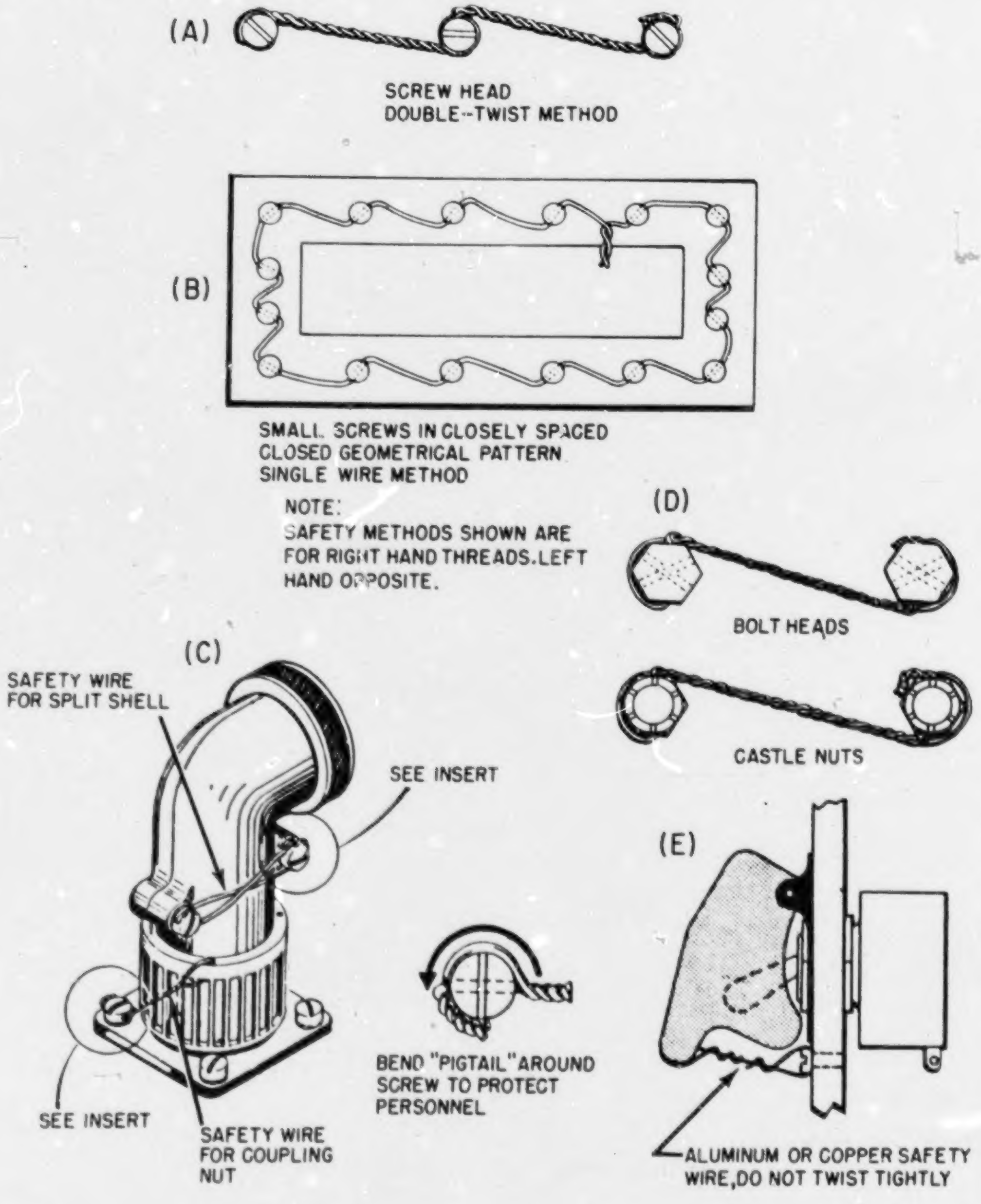
Shock absorbing materials commonly used in shock mounts are usually electrical insulators. For the sake of safety, it is required that each electronic unit mounted in this manner must be electrically bonded to a structural member of the aircraft. (See fig. 6-11(B).) The bonding strap should also be included in the inspection of the shock mounts, and defective or ineffective bonds should be replaced or reinstalled.

SAFETY WIRING

Before an installed unit can be considered secured for flight, it must be safety wired properly. Two common methods—the single twist and the double twist—are used. Figure 6-12 illustrates typical examples of each method.

Specific items which normally require safety wiring include cable connectors, drilled-head bolts or screws and nuts, thumbscrews and wingnuts on mounting racks, switchguards which are required to retain a switch in a specified position but which could be placed inadvertently into the wrong position, and most threaded items which do not use cotter pins or self-locking nuts.

The double twist method is the most common method of safety wiring, and should essentially be as shown in figure 6-12(A). The twisting may be accomplished by hand with the exception of


(A)
SCREW HEAD
DOUBLE-TWIST METHOD
(B)
SMALL SCREWS IN CLOSELY SPACED
CLOSED GEOMETRICAL PATTERN
SINGLE WIRE METHOD
NOTE:
SAFETY METHODS SHOWN ARE
FOR RIGHT HAND THREADS. LEFT
HAND OPPOSITE.
(D)
BOLT HEADS
CASTLE NUTS
(C)
SAFETY WIRE
FOR SPLIT SHELL
SEE INSERT
SEE INSERT
SAFETY WIRE
FOR COUPLING
NUT
BEND "PIGTAIL" AROUND
SCREW TO PROTECT
PERSONNEL
(E)
ALUMINUM OR COPPER SAFETY
WIRE, DO NOT TWIST TIGHTLY

AT. 273

Figure 6-12.—Safety wiring methods.

the final few twists which should be done with pliers in order to apply tension and secure the ends of the wire properly. The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolthead, causing a slack loop. Extreme care must be used when twisting the wires together to insure that they are tight but not overstressed to the point where breakage will occur under slightly greater than normal load or vibration.

The single twist method of safety wiring may be used on small screws in a closely spaced area, if the screws form a closed geometrical pattern. Figure 6-12(B) illustrates a typical application where the single wire method may be used.

Finished ends of safety wire should be bent back or under to prevent injury to personnel (fig. 6-12(C)). The safety wire should be as short as practicable, and must be installed in such a manner that the pull on the wire is in the direction which tightens the movable item (fig. 6-12(D)).

When safety wiring widely spaced bolts by the double twist method, a group of three should be the maximum number in a series. When safety wiring closely spaced bolts, the number that can be safety wired by a 24-inch length of wire should be the maximum number in a series.

Torqued parts being safety wired should be torqued to recommended values and holes alined before attempting to proceed with the safetying operation. Never overtorque or loosen a torqued nut to aline safety wire holes.

Whenever a safety wire is broken for maintenance or other cause, it must be replaced using the proper procedure. Any time a required safety wire is not replaced, an in-flight failure may result.

MISCELLANEOUS PROBLEMS

Generally, problems of the mechanical type are caused from excessive wear or carelessness on the part of the technician.

Installation of Equipment

Although itemized installation procedures are listed in the Maintenance Instructions Manual for each model aircraft and equipment, this phase of the maintenance process presents a great deal of trouble. Most of the troubles in this category result from carelessness and oversight on the part of the technician. Specific instances are loose cable connections, switched cable terminations, improper bonding, lack of (or improper) safety wiring, remote switches in the wrong positions, failure to perform an operational check after installation, failure to pressurize specified units, etc.

Two additional points concerning installation of equipment in aircraft need emphasis. Prior to reinstalling any unit or component, inspect its mounting for proper condition of shock mounts and bonding straps. After installation, safety wire as appropriate.

Disassembly and Reassembly

Problems are encountered in the removal and replacement of units in the aircraft and the disassembly and reassembly of subunits in the work center. Some of these problems are considered in this discussion. Most of these problems are created by the technician because of either carelessness or lack of understanding on his part.

One of the problem areas is the threaded fasteners used in the mounting of parts or subunits. Broken or stripped bolts, damaged heads or threads, etc., hamper the disassembly and reassembly process. The use of the proper tools and techniques are very important in keeping this problem to a minimum.

Some units that contain autotune systems that mechanically tune more than one subunit are a problem if these subunits are not properly alined mechanically before insertion into the autotune mechanism. If these subunits have mechanical stops and are inserted into the autotune system improperly, they can be damaged.

Pin or plug alinement before insertion into its mate is necessary if damage is to be prevented. Some of these pins are very small and delicate and will not withstand any bending or distortion without breaking. Some subunits or modules have different pin arrangements though their shell dimensions may be identical; therefore, great care must be taken to insure that the subunits or modules are installed in the proper location.

Coaxial connectors can also be a source of problems. When connecting or disconnecting these connectors, always use great care that the coaxial cable is not separated from the connector. Miniature coaxial connectors can be damaged very easily if handled roughly during connection or disconnection.

ENVIRONMENTAL PROBLEMS

Although the need for reliability in military avionics equipment has remained relatively constant over the years, the difficulty of attaining this reliability has increased. The continually increasing complexity of avionics equipment and the subjection of equipment to more and more rigorous environmental conditions are among the chief causes of equipment failure. For these reasons the technician should understand the effects of environmental conditions on the equipments and the design techniques used to minimize these effects.

The environmental factors that should be understood in order to maintain the design characteristics include temperature, humidity, pressure, and abrasive conditions.

TEMPERATURE

Extensive research has been conducted to develop external component parts that are better able to withstand operation under extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility of rubber, insulation, and similar materials. Extremely high temperatures may cause deformity and deterioration of these items. Most internal component parts are not able to withstand these extreme temperatures.

Because equipment is normally installed in confined spaces aboard aircraft, the generated heat causes the temperature to rise; therefore, many units have fans installed to increase the air circulation, thus reducing the temperature within the unit. Most of the new models of aircraft utilize the electronic equipment compartment concept, and use blast air from outside the aircraft or from the aircraft's air-conditioning system for cooling.

HUMIDITY

Humidity, a measure of water content in the air, is a possible cause of avionic equipment or component failure. High humidity also provides a possible environment for corrosion and fungus growth.

In certain cases the removal of heat from equipment requires the use of external air. If this external air has a high moisture content, the cooling may be accomplished by one of two ways. First, the high humidity air may be directed through an air jacket which surrounds the equipment. In this case the heat is removed without allowing the humid air to come in contact with the internal equipment components. Second, when the internal equipment components require direct air for heat removal, the direct air is passed through silica-gel crystals, removing the moisture from the air. It should be apparent that the second method is less troublesome because the first case does cause corrosion within the air jacket.

PRESSURIZATION

When high-voltage avionics equipment is operated at high altitudes without being pressurized, there may be the problem of arc-over. This is caused by the reduced dielectric strength of the air as it becomes less dense. To reduce the possibility of arc-over, the equipment is pressurized.

When troubles occur in the system, a check for evidence of arc-over should be made. This may be indicated by blown fuses, charred insulation, and pitting of metal close to high voltages.

ABRASIVE CONDITIONS

Sand, dust, and other substances which are abrasive in nature affect many components. Generally these components are parts that are not sealed off from the atmospheric conditions. In some cases the abrasive material is formed even though the unit is sealed. Examples are generators, motors, and dynamotors which use brushes. Also the protective coating may be removed from a part by the movement of the abrasive material in the air that is used for cooling. This may allow the unprotected metal to corrode.

Modern aircraft configurations employ the use of air-conditioning systems for the purpose of cooling the avionics equipments. The external air is used to cool the heat exchanger while the internal air used to remove heat from the equipment may be pressurized. The use of the pressurized air for equipment heat removal minimizes the undesired environmental effects of temperature, humidity, arc-over, and abrasive conditions. (Air-conditioning systems are discussed in chapter 8 of this manual.)

CORROSION CONTROL

In modern aircraft, the need for corrosion control has become a major concern in the availability and maintenance of our striking forces. This is because corrosion is something that destroys equipment and is active 24 hours a day. It is of the utmost importance that its nature be understood in order to combat corrosion.

Most of the useful metals used today have been refined from natural ores found in the earth's surface. These metals are extracted from the ore and are used in various combinations to form alloys with distinct properties. Some of these properties are light weight, strength, and resistance to extreme temperatures. These refined metals have a tendency to return to their natural state, but proper corrosion control will prevent this action taking place.

With the strength demands being made of metals, corrosion control becomes more important because corrosion weakens the metals, thereby causing structural failure. This type failure will cause aircraft safety to decrease and cost of repairs to increase.

CHEMICAL CORROSION

Most surface corrosion is chemical in nature and is generally caused by salts, acids, or gases coming in contact with the metallic surfaces of the aircraft or equipment.

Aircraft and their associated equipment which are based aboard ship are particularly vulnerable to salt spray and gases which originate on board a ship. Shore-based aircraft are also exposed to contamination, but to a somewhat lesser degree. Although salt spray and gases in the atmosphere cause rapid chemical corrosion, it should be understood that some corrosion will take place under the most ideal situations.

Chemical corrosion is a chemical process which is essentially the reverse of the process of extracting the metals from their ores. For the most part, metals occur naturally as metallic oxides. After refining, regardless of whether or not alloyed, base metals generally possess a tendency to return to their natural state. However, this is not sufficient in itself to initiate and promote this reversion. There must also exist a corrosive environment in which the significant element is oxygen. Corrosion, then, is the process of oxidation.

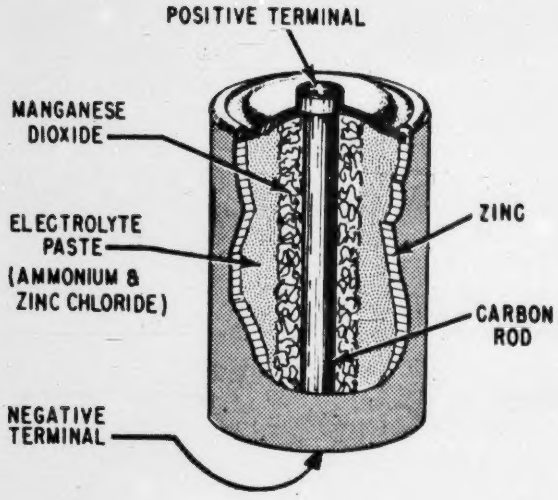
ELECTROCHEMICAL CORROSION

While chemical corrosion is generally readily apparent, electrochemical corrosion is insidious in its destruction. Electrochemical corrosion includes galvanic or dissimilar metals corrosion. This type of corrosion is caused by an exchange of electrons between two metallic areas of different activity (potential) by way of an electrolyte. Three conditions must be present in order for electrochemical corrosion to take place. The first condition is that two or more areas of metal are needed to act as electrodes. The second condition is the requirement of the presence of an electromotive force. The last requirement is the presence of an electrolyte to complete the formation of a cell.

It is not necessary to know all the theories concerning electrochemical corrosion, but a brief understanding of the deterioration of metals will be beneficial in combating this type of corrosion.

An ordinary flashlight cell serves as a good subject to explain electrochemical corrosion. (See fig. 6-13.) The outside container is made of zinc and serves as the anode which is corroded as the cell is operated. The cathode of the chemical cell is the carbon electrode in the center of the cell. The moist ammonium and zinc chloride paste within the zinc container is the electrolyte which electrically connects the carbon electrode with the zinc anode.

If a conductor is connected externally to the electrodes of a cell, electrons will flow under the influence of a difference of potential across the electrodes from the zinc (-) through the external



AT.274

Figure 6-13.–Dry cell, cross sectional view.

circuit to the carbon (+) returning within the electrolyte to the zinc. As the electrons flow, the zinc coating will oxidize. This oxidation is the same as corrosion.

Since the only requirements for a cell are cathode, anode, and electrolyte, it should be apparent that the physical size of a cell is dependent only on the physical size of its components. A cell may be formed where a resistor lead is soldered to a terminal, two sheets of metal are joined, or around a rivet head and the adjacent metal. (See fig. 6-14 (A) and (B).) A cell may even be formed when an electrolyte is present on one piece of metal where two metallic crystals in the same alloy, but of different composition, are in electrical contact with each other. (See fig. 6-14(C).)

While the formation of one minute cell may be insignificant, it should be understood that a cell will continue to grow as long as the corrosion action is allowed to continue. This cell expansion may take place in a short period of time and become a significant structural safety factor due to the deterioration of the metal.

It should be apparent that the presence of an electrolyte allows corrosion to take place. The more efficient the electrolyte and the greater the potential difference between anode and cathode, the higher the corrosion rate will be. It should be noted that the anode and cathode are always present and cannot be removed; therefore, the solution to the problem of corrosion is to remove the electrolyte. When the electrolyte is removed, a cell no longer exists and corrosion is held to the minimum.

Both types of corrosion normally depend on moisture to form an electrolyte. Even moisture in the air is often sufficient to start the corrosive action. In general, corrosive action begins on the surface of the metal and works to the core. Therefore, the appearance of the surface is usually the first indication of corrosion.

CORROSION PREVENTION

Now that it is understood that the "villain" of corrosion is the electrolyte, the solution to corrosion prevention is to keep any electrolyte from coming into contact with the electrodes. This is accomplished by keeping a protective coating on the metallic surfaces.

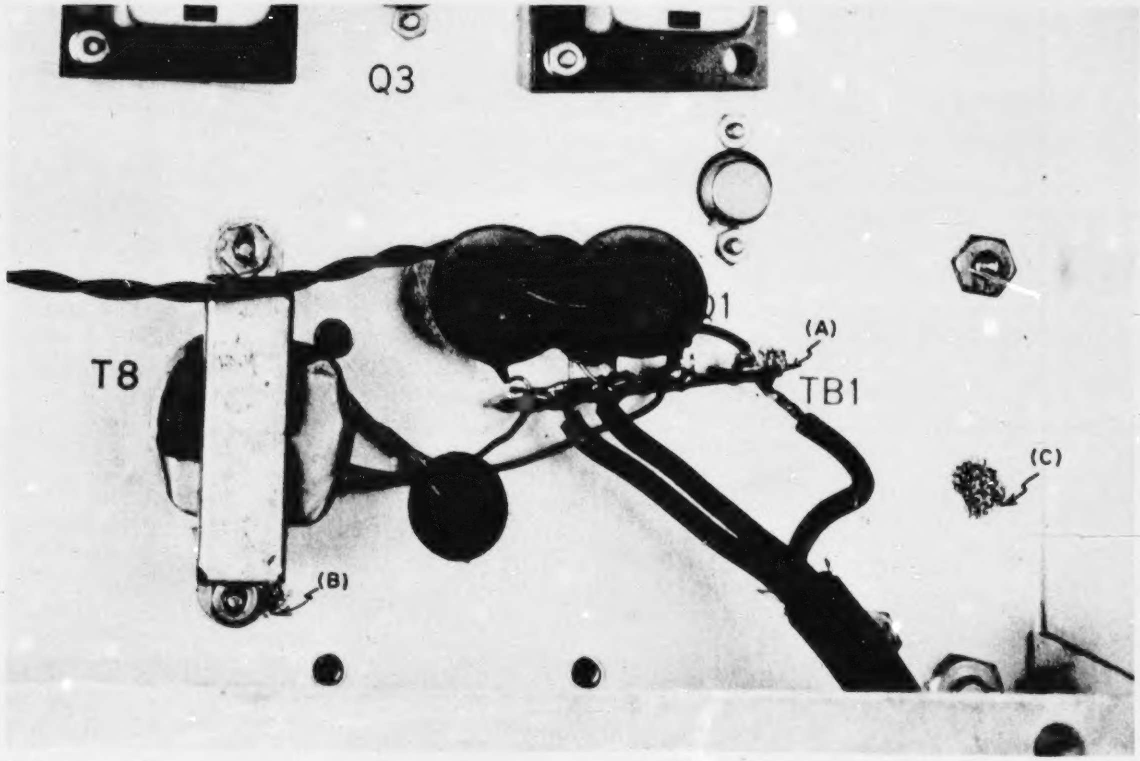
Much has been done to improve the corrosion resistance of naval aircraft. This is in the area of improvement in materials, surface treatments, insulation, and protective finishes. All of these have been aimed at reducing maintenance effort as well as improving reliability. In spite of these improvements, corrosion and its control are very real problems that require a continuous preventive maintenance program.

Corrosion preventive maintenance includes the following special functions:

1. An adequate cleaning program.
2. Thorough periodic lubrication.
3. Detailed inspection for corrosion and failure of protective systems.
4. Prompt treatment of corrosion and touch-up of damaged protective coating.

Inspection

Inspection for corrosion is a continuing problem and should be handled on a day-to-day basis. Overemphasizing a particular corrosion problem when it is discovered, and then forget-



AT.275

Figure 6-14.—Electrochemical corrosion.

ting about corrosion until the next crisis, is an unsafe, costly, and troublesome practice.

Most periodic maintenance requirement information has been placed on Maintenance Requirements Cards which are complete enough to cover all equipments in the aircraft. No equipment of the aircraft should go unchecked. Through experience, it will be learned that most equipments have trouble areas where corrosion will occur. Equipments in helicopters are particularly susceptible to corrosion due to the tactics which the helicopters utilize.

Protective Measures

An effective protection from corrosion requires the earliest possible repair of damaged protective coatings, including the removal of corrosion products and the restoration of corroded surfaces. This involves the maximum use of supplementary protective agents during any waiting periods or until such time as more positive protection can be restored. It must be a continuous program and recognized as a specific responsibility.

Periods of neglect or touchup maintenance, which may be necessary under operating conditions, should be followed by a period of concentrated effort to correct any deficiencies which have started. A successful preventive maintenance program will tend to reduce the effects of severe service environments and the susceptibility of most aircraft and equipment to damage by these environments.

ANTICORROSION MATERIALS.–During manufacture, electronic equipments are usually sprayed with a protective coating that seals out moisture, thus preventing corrosion and fungus growth. In repair of these equipments, it is sometimes necessary to remove the protective coating by scraping or by the use of a solvent cleaner.

After making circuit repairs, the protective coating should be replaced. Rosin fluxes form coatings on solder connections that prevent oxidation during and after the soldering process, thus providing one form of replacement. A good general rule is that materials used should be those covered and controlled by military specifications, preferably those authorized specifically for use on aircraft. Use nonspecification materials only in emergencies, or where specific instructions so direct.

FUNGUS-RESISTANT MATERIALS.–Fungus susceptibility of materials has long been a serious problem, particularly with electronic equipments which may be subjected to extremes of humidity under tropical temperatures. While the fungus itself is objectionable since it generally is a source of trouble that affects all types of equipment, its most serious effect is the increased possibility of shorting and arcing because of its moisture content.

The fungus problem has been further aggravated in the past decade by the increased use of a large number of organic materials in equipment used by the Navy. These materials vary in nature and size from large sheets of reinforced plastic for structural components to special dielectric substances used in complex electronic gear.

Fungus removal generally follows the same procedures of corrosion removal.

CORROSION REMOVAL

In corrosion control, time is of the essence. Until the electrolyte is removed, the chemical reaction will continue. Although the ultimate goal is complete removal of the electrolyte, it is possible some will remain in inaccessible locations of the chassis or modules making the cleaning process particularly difficult.

When this occurs, the proper procedures and cleaning materials must be used. The remainder of this discussion will be devoted to the techniques and materials used in correcting this problem.

The extent of cleaning, using the following techniques, requires the decision of the Corrosion Control Officer assigned to the organization.

Dry Cleaning

When corrosion or salt crystals are discovered in a piece of equipment, as much of this as possible should be removed by dry methods. This entails breaking the solids from the metallic parts by wiping with a dry cloth or brushing with a stiff bristle brush. Care should be taken not to damage any of the components of the equipment.

Any loose residue should be removed by the use of low pressure dry air.

Although it may appear that all of the contamination has been removed, this generally is not the case. At this point a decision must be made as to the possibility of contamination existing in the inaccessible or undetectable areas of the equipment. If this decision indicates that contamination still remains in the equipment, then further steps must be taken in the form of liquid cleaning.

Fresh Water

Although immersion or flushing of electronic and other equipment in or with water violates previous training, fresh water is one of the agents used to remove salt water and deposits from equipments. After the equipment has been subjected to fresh water, the water must then be removed. This may be accomplished by dry air pressure, by the use of a spray (displacement) fluid, or by a drying oven.

DRY AIR PRESSURE.–Any type of compressor that will deliver clean dry air at 80 psi will be adequate to furnish air for spray cleaning and for blowing as much water as possible from the wet equipment before using the water-displacing fluid.

WATER-DISPLACING FLUID.—This fluid is generally available in pressurized aerosol cans or in drums and is called a spray-dry water-displacement composition. A paint spray gun or other spraying equipment for applying bulk water-displacing composition in a fine mist may be used if an aerosol-pressurized water-displacing composition is not available.

The equipment is sprayed with this composition, and then some means of drying such as heat oven, air pressure, or natural evaporation should be used.

DRYING.—Forced draft ovens with accurate temperature control large enough to accommodate the equipment being cleaned are preferred for final drying of the cleaned equipment. If ovens are not available, a small room equipped with an exhaust fan and heaters can be used. The temperature in the drying facilities should be between 120° and 160° F, depending upon the temperature sensitivity of the equipment being dried. If a heated room is used for drying, its temperature should be at least 30° F above the ambient temperature.

Detergent

In some cases a detergent must be used. The detergent is available in aerosol type containers or in bulk form. Detergent is used when salt crystals have formed on the equipment or an oily deposit is present in the equipment. The detergent will dissolve the salt crystals and will also emulsify and suspend oil deposits in the solution. In either case, fresh water must be used to rinse the contaminated solution from the equipment.

Ultrasonic Tanks

An ultrasonic tank is a container for fresh water or a cleaning agent. The solution is vibrated either by a transducer or by forced air. The agitation helps remove particles from inaccessible areas of the electronic equipments. The frequency of the transducer is in the ultrasonic range and accomplishes the cleaning in a much shorter period of time than the forced air. When equipment has been removed from an ultrasonic tank, the previously mentioned procedures for drying should be completed.

SALVAGE PROCEDURES

The following steps comprise the routine procedure for salvaging sea water contaminated electronic equipment:

1. Immediately after removal of the equipment from sea water contamination, the equipment should be flushed thoroughly with fresh water.
2. The equipment should be disassembled to units of a size that permits immersion in an ultrasonic bath and to allow better access of cleaning solutions.
3. Remove contamination with emulsion cleaning composition in the ultrasonic tank.
4. Rinse in an ultrasonic tank of fresh water or rinse with a fresh water spray.
5. Blow the rinse water from the equipment with clean compressed air and follow with an application of water displacing composition.
6. Dry in an oven or by natural evaporation.
7. Check for damage, repair and lubricate as required, then return to service.

Equipment which cannot be dismantled or is too large for cleaning in the ultrasonic tank can often be cleaned by spraying with a cleaning emulsion. Upon completion of the emulsion application, the equipment should be rinsed and dried as previously indicated.

CARE AND SERVICING

The operating quality, stability, and reliability of electronic equipment are strongly affected by the quantity and quality of maintenance. Shiny dials and polished handles may be impressive, but it is the care and upkeep of the equipment behind the front panel that determines the operational capabilities of an electronic system.

The minimum requirements for routine care and servicing are listed in the inspection requirements for aircraft and in the technical manuals for specific equipments. The discussion in this chapter is limited to specific items that present special problems or that require special techniques.

SPECIFICATIONS AND PROCEDURES

Detailed instructions, procedures, and specifications for the care, handling, stowage, and servicing of electronic items of equipment are contained in the Maintenance Instructions Manual for each equipment and for each aircraft in which that item is installed. All such procedures must be followed exactly; the specifications must be closely observed. Some components, however possess certain characteristics which warrant special discussion in this context. It must be noted that many of the considerations listed in the following discussion as applying to specific components are, in fact, general considerations which apply to many other components as well.

SPECIAL COMPONENTS

The purpose of this discussion is to provide the information needed to handle magnetrons and other electron tubes properly and to understand why careful handling is necessary. Most of the information supplied may also be applied to other items of electronic equipage.

Magnetrons

Although magnetrons are usually large and heavy, and appear to be rugged, they are actually extremely delicate items. Many of the individual parts are very delicate, and they must remain in precise alinement if the magnetron is to operate properly. Jars, jolts, and vibrations can cause misalinement and render the magnetron useless. The magnet itself, although made of solid metal, can lose its magnetic strength if improperly stowed or handled, resulting in poor performance of the magnetron.

Manufacturers of magnetrons are required to package them according to very rigid specifications. The containers are designed to give the magnetron mechanical support to prevent crushing damage, resilient support to cushion it against shocks and vibrations, and a safe minimum distance from other magnets or ferromagnetic materials. (Magnets stowed close together or close to steel shelves, bulkheads, or other ferromagnetic objects will gradually lose their magnetic strength.)

A magnetron should be retained in its original container until needed for immediate installation. It should not be removed from its carton to conserve space and weight, but should be stowed in the complete container, regardless of the weight and space factors involved.

When unpacking a magnetron for immediate installation, all parts of the container—the outer and inner casings, the support brackets and braces, the mounting hardware, the plastic covers for receptacles and mechanical connectors, the cushion materials, etc.—should be retained for packing the magnetron removed from service.

Magnetrons which have been removed from service are often returned to the manufacturer or some other activity for analysis. These magnetrons must be treated in the same manner as when new—magnetrons damaged after removal from service cannot be analyzed for the cause of original failure. The container should be plainly marked to indicate that it contains a used tube.

Whenever a used magnetron is reshipped, it must be accompanied by all papers and records pertaining to its performance history, hours of operation, and reason for removal. Such paperwork is valuable in the analysis of the failure, and results in improved reliability of magnetrons.

Although the ceramic window and insulator are convenient places on which to make notations, such markings form conduction paths which can cause arc-over; therefore, notations should never be made at these locations. (If notations are deemed necessary, use a tag tied at a convenient and acceptable location, or tacked to the outer container.)

Magnetrons themselves are not sensitive to either high or low temperatures. However, to avoid possible damage from freezing, liquid-cooled magnetrons must be thoroughly drained and dried before repacking and stowage. If the coolant does not contain an antifreeze, the magnetron should be flushed with ethylene glycol or alcohol before drying in case some liquid remains trapped in the cooling jacket. These steps should be taken any time a magnetron is repackaged, whether for reshipment or for stowage.

CRYSTAL MATCHING

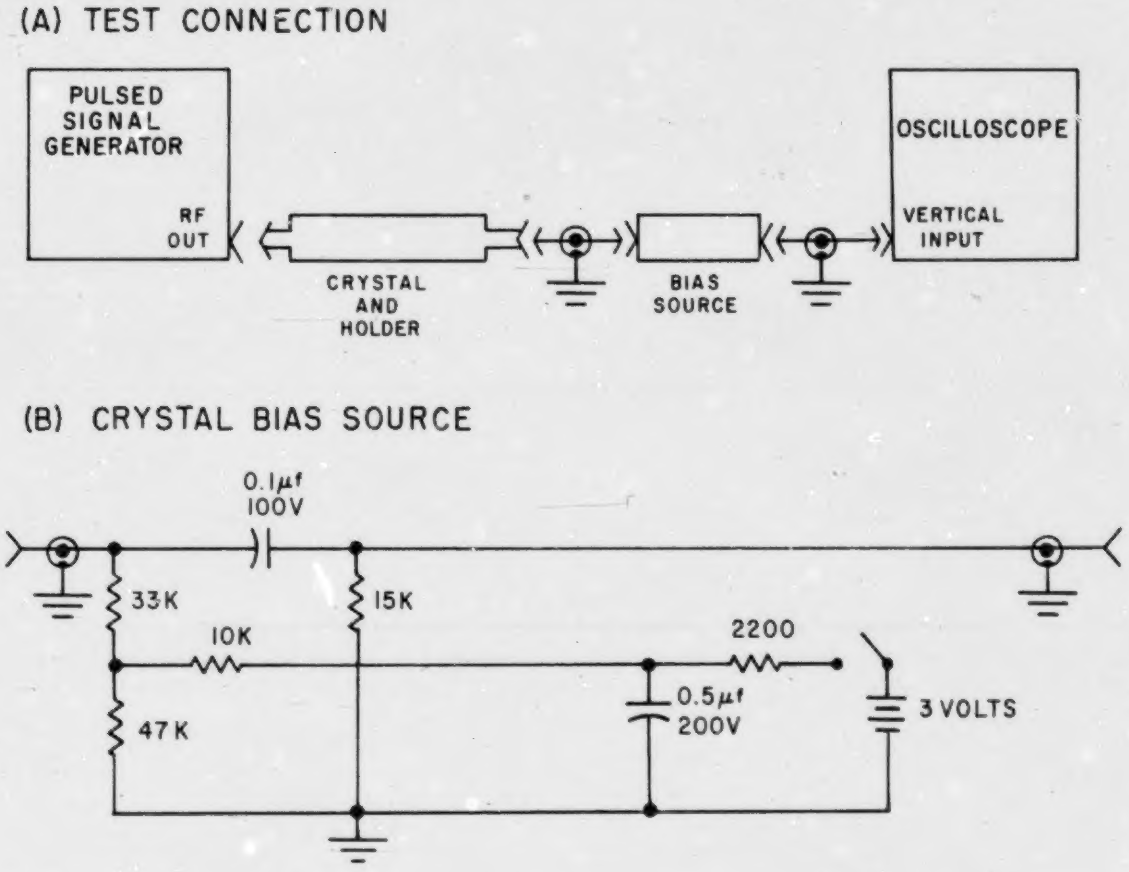
Many pulsed microwave equipments require matched sets of detector crystals for satisfactory operation. The matching of crystals may be accomplished under operating conditions, without elaborate calibration procedures, using normally available test equipment. In this discussion "matching" indicates that if the same amount of pulsed RF energy is applied to two or more detector crystals, the output pulses will not vary by more than a given ratio. If a given signal produces a 0.004-volt peak-to-peak pulse from one crystal and a 0.005-volt peak-to-peak pulse from a second crystal, the ratio is 5 to 4, or 1.2. Converting this to decibels,

$$20 \log 1.2 = 20 (0.08) = 1.6 \text{ db}$$

Thus these crystals match within 1.6 db.

A practical method which is usable is indicated in figure 6-15. It is used to measure the calibrated power (supplied by the pulsed signal generator) required to produce a prescribed output (indicated on the oscilloscope). If two crystals require -15.5 dbm and -16 dbm, respectively, to produce a 0.004-volt peak-to-peak pulse, these crystals match within 0.5 db.

The signal generator used will depend on the frequency or frequencies where matching is desired. The crystal holder, bias source, and oscilloscope used will depend upon what is available and what crystals are being matched. Figure 6-15(B) shows a bias source which may be local-


(A) TEST CONNECTION
PULSED SIGNAL GENERATOR
RF OUT
CRYSTAL AND HOLDER
BIAS SOURCE
OSCILLOSCOPE
VERTICAL INPUT
(B) CRYSTAL BIAS SOURCE
0.1μf 100V
33K
15K
10K
2200
47K
0.5μf 200V
3 VOLTS

AT. 276

Figure 6-15.—Crystal matching procedure.

ly made if a ready-built one (such as the AN/USA-7 unit No. 1) is not available.

TESTING

The term testing, as used in this section, refers to the use of associated equipment to determine or to evaluate the condition or quality of operation of a unit, circuit, or component. Proper testing procedures must begin with the selection of the test equipment. This equipment must be used according to specific instructions. The testing must follow detailed procedures. The results must be evaluated in light of itemized specifications.

The following paragraphs discuss some aspects of the selection of proper test equipment, followed by some special considerations in the testing of certain circuits and components.

SELECTION OF SUPPORT EQUIPMENT

The first requirement of any support equipment is its ability to perform the test required; secondly, it must be compatible with the equipment under test. Chapter 5 of this manual is devoted to a discussion of test equipment. The present discussion is confined to the compatibility between test equipment and the equipment under test, followed by some factors regarding the evaluation of the results of certain tests.

Impedance Matching

Closely associated with circuit loading is the idea of impedance matching. As it pertains to test equipment usage, impedance matching involves the reactive components as well as the resistive component of circuit impedance. For a maximum transfer of power the resistance of the source must equal the resistance of the load and the reactive components must cancel. However, in many testing situations this condition is undesirable.

Most items of electronic equipment and test equipment are rated according to input and/or output impedances. Coaxial cables and coaxial adapters are usually supplied with test sets normally used in testing of electronics equipment. The test procedures which govern the use of a specific equipment for a specific test on a particular equipment contain itemized lists of the items required. Use of the specified items provides adequate impedance matching.

As mentioned previously, the cables and fittings supplied with a given test set should be used with that set. Substitution of cables frequently causes mismatching of impedance and results in erroneous test results.

Frequency

Another important consideration in the selection of test equipment involves the respective frequency ranges of the test set and the equipment under test. Signal generators must supply frequencies within the response band of tuned circuits; frequency meters must be responsive to the frequencies in the outputs of tuned circuits.

Amplitude

The output signal magnitude of the generator must be large enough to cause a response in the circuit under test. To test the output of that circuit, the test set must have sufficient sensitivity to respond to the signal. In either case, however, signal amplitude must not be so large that it overdrives or damages the equipment. If signals are too large, reduced coupling or increased attenuation may be used to reduce its size. This change must be considered in any evaluation of the test.

Polarity

Many nonsinusoidal signals are used in electronics equipment. Test equipment used in checking circuit operation must be capable of generating (or responding to) the proper polarity input. An example of this requirement is found in the triggering signals of radar synchronizers. Signals having the wrong polarity fail to activate the triggered circuit, and may erroneously indicate a malfunctioning circuit.

CIRCUITS AND COMPONENTS

The most frequently encountered areas of testing are concerned with tubes, tuned circuits, and power measurements.

Testing of Electron Tubes

The condition of a tube can be determined by substituting a tube known to be good for the questionable one. However, indiscriminate substitution of tubes is to be avoided, as detuning of circuits may result. In addition, a tube may not operate properly in a high frequency circuit, although it performs well in a low frequency circuit. Therefore, in order to service electronic equipment, a knowledge of tube testing devices and their limitations, as well as correct interpretation of the test results obtained, is indispensable for accurate job performance.

In order to determine the condition of an electron tube, some method of testing is necessary. The operating capabilities (and design features) of a tube are shown by its electrical characteristics. A tube is tested by measuring its characteristics and comparing them with representative values established as standard for that type of tube. Tubes which read abnormally high or low with respect to the standard are subject to suspicion. Practical considerations take into account the limitations of the tube test in predicting actual tube performance in a particular circuit. For most applications the testing of a single tube characteristic is enough to determine whether a tube is performing satisfactorily.

It should be kept in mind that a tube-testing device only compares the characteristic of a given tube with a standard for that particular type of tube. Since the operating conditions imposed upon a tube may vary over wide limits, it is not possible for the tube tester to evaluate a tube in terms of performance capability for all applications. Therefore, the tube tester is not always considered the final authority in deciding whether or not a tube is satisfactory. Substituting a good tube in the equipment, and observing the performance of the equipment, provides the most reliable evidence concerning the condition of the tube in question. Substitution is also the only method for testing many high power tubes used for transmitter applications. Nevertheless, the tube tester plays a very important function in most cases because it provides a quick and satisfactory check on tube serviceability.

Alinement of Tuned Circuits

Tuned amplifier, oscillator, detector, and filter circuits must be properly adjusted for optimum performance of electronic equipment. The signal generator, in conjunction with various indicating devices, is used for most alinement procedures in receiving equipment. Transmitter oscillators can be tuned to the correct frequency by frequency measuring instruments and transmitter amplifier stages can be adjusted by means of output meters or grid and plate current measurements. However, it is something advantageous to tune transmitter amplifier stages by injecting a known signal from a signal generator in the same manner that receiver amplifier stages are tuned. The type of test equipment necessary for a particular tuning procedure is determined by frequency, power level, accuracy, allowable distortion, and modulation requirements.

The principal purpose of a signal generator is to provide a known signal with adjustable characteristics. There is need, on occasion, for square or other nonsinusoidal waveforms; however, in general, test procedures require the use of sine waves of variable frequency and amplitude.

The need for tuning electronic equipment may be indicated by reduced levels in signal outputs; however, alinement procedures should not be undertaken before general operating tests are made. Every equipment that is operating poorly requires maintenance, but it does not follow that every equipment that needs maintenance also needs alinement. Repairs which require the replacement of parts or the redressing of wiring may make subsequent alinement necessary. Therefore, no alinement should be attempted until all apparent troubles have been corrected and all defective parts replaced. Haphazard attempts at alinement by inexperienced or careless personnel may do more harm than good, and may increase the time required for making relatively minor repairs. Before alinement is attempted, all available instructions should be carefully consulted.

Power Measurement

One very common error in maintenance and in testing is the tendency to underestimate the meaning of decibel readings. As an example, test specifications for a particular portion of the testing procedure of a radar set might call for a decibel reading of 75 db. Upon performing the test in exactly the prescribed manner, it is determined that the decibel reading is 72 db. Too many technicians tend to assume that "this is good enough." It must be remembered, however, that a decrease (in power level) of 3 db represents a 50 percent reduction in power. This condition is intolerable when performing most tests.

SYSTEMS TESTING

Combinations of communication and electronic equipment and facilities are interconnected to form systems capable of performing specific functions. To meet reliability requirements and to comply with operating restrictions, technical personnel must be able to apply general test methods and practices to the installation, tuning, and maintenance of these combinations of equipment and facilities. This may entail a knowledge of many types of communication, and electronic equipment. Radar, communication and other types of electronic equipment, when interconnected, may require different maintenance procedures than when operated separately. Revised test procedures may be necessary, any detrimental interactions between equipment or facilities must be corrected, and effective preventive maintenance must be programed for all equipment and facilities within the system. System quality figures, such as sensitivity and coverage, must be initially determined and measured during equipment preventive maintenance checks to assure efficient operation.

Receiver Sensitivity

The one measurement which provides maximum information about receiver condition in field operation is that of sensitivity. This measurement ordinarily requires the application of an input signal of variable voltage to the antenna terminals of the receiver, through an impedance which approximates that of the antenna with which the receiver is designed to be used. Any external impedance which is added to the signal-generator impedance to simulate the antenna impedance is usually known as a dummy antenna. It insures that the signal current in the input circuit of the receiver is the same as would appear with the known signal induced in an ideal receiving antenna, and it also insures that the input circuit of the receiver is "loaded" the same as it would be by an ideal antenna.

CONDITIONS FOR SENSITIVITY MEASUREMENT.—For measurement of sensitivity, the receiver is adjusted for the type of reception desired, and facilities such as tone controls or audio filters, AGC, silencer, noise limiter, etc., are placed in or out of operation as required or are set at appropriate control positions. The power-line voltage applied to the receiver should be well within the normal recommended operating range. The receiver output terminals should be properly loaded. At the headphone or audio-line terminals, unless otherwise specified in the instruction book for the equipment, the load should be a 600-ohm noninductive resistor capable of continuously dissipating the maximum receiver audio power output that can be produced at these terminals. High-impedance headphones may be used in shunt with the load for monitoring the output. Low-impedance phones may load the output appreciably and may have to be removed when data are being taken. The output voltage should be measured with a high-impedance audio voltmeter, capable of accurate indication from 0.1 volt to 100 volts, that will not appreciably load the output circuit. Although some receivers are equipped with audio-output meters, the meters provided may not indicate required standard noise levels with sufficient accuracy.

RECEIVER SENSITIVITY TESTS.—Receiver output power is measured, as part of a sensitivity test, to determine whether the receiver is performing according to the required sensitivity specifications. The sensitivity is the value of signal voltage fed to the antenna terminals that will produce a specified power output at the receiver output terminals with a signal-to-noise ratio of 10:1. A simple way to check audio-power output is to use an a-c voltmeter across a resistor of the correct value, as specified in the instruction manual. With the signal generator delivering an input voltage to the receiver antenna terminals, the voltmeter measures the output voltage across the resistor. The power output is then computed by using the formula $P = E^2/R$.

Transmitter Power Output

Electrical power delivered to a load at any instant is equal to the product of the voltage across the load and the current passing through it, or $P = EI$. Under stable d-c conditions, this product is also equal to the average power consumed. In a-c circuits, on the other hand, the presence of either inductive or capacitive reactance means that the apparent power, EI, where both voltage and current are rms values, must be multiplied by a number called the power factor to obtain the true power. Briefly, this is necessary because pure inductors and capacitors store energy furnished by the line and, during a later portion of the cycle, restore such energy to the line. If purely reactive circuits were possible, none of the power would be dissipated. Naturally, resistance is an unavoidable component of any reactance, so from a strict standpoint nondissipative networks are not attainable. In practical a-c circuits, the power dissipated is equal to the apparent power multiplied by the cosine of the phase angle between the voltage and current.

Calibrated voltmeters and ammeters are used as a direct approach to power measurements in d-c circuits. Usually, approximate indications of power are satisfactory in electronic circuit work, so that neither the expense nor the inconvenience of two separate meters is justified. A typical instance is that of determining whether the power rating of a resistor is adequate. It is generally acceptable to measure the voltage across the resistor and then to calculate the power by the basic equation $P = E^2/R$. For current rather than voltage measurement, the power is equal to I^2R. If the designated resistance of the part is not sufficiently reliable, it may be measured approximately with an ohmmeter. Conceivably, an extremely accurate measurement may be required, in which case a determination by means of a Wheatstone bridge can be made. Similarly, it may be necessary to determine the a-c power dissipated by a resistive load, either at audiofrequency or radiofrequency. The same method is reliable, provided the resistance of the device is known at the frequency in question.

Power Supply Measurements and Adjustments

Power supplies that are commonly used in avionic equipment are either regulated or unregulated. An unregulated supply usually provides filtered but unregulated low B-plus (under 300 v d.c.) or high B-plus (over 300 v d.c.) in addition to a-c heater power for vacuum tubes and in some cases relay-operating power. The regulated power supplies consist of an unregulated supply and the associated circuitry necessary to regulate the B-plus output.

Power supplies used to provide the d-c voltage sources for operation of electronic equipments are of various types, such as half-wave and full-wave rectifiers. The type circuitry employed for a particular application depends on such factors as current and voltage load requirements, available space, weight, degree of voltage regulation required, etc. Electronic systems are generally complex and contain one or more power supplies which provide several voltage outputs. The design performance of these equipments depends upon the proper operation of the power supplies. For this reason, power supply tests are included in the preventive maintenance test procedures prepared for most equipments. Many equipments are provided with easily accessible test points for ease in performing these tests. The more common type of power supply test is a simple voltage reading taken with the equipment in operation.

To operate radar equipment, various d-c voltages are required. The transmitter requires a high voltage source capable of delivering a large current for short intervals of time. The regulation or ripple content of this voltage is not critical. The cathode ray tube requires a high accelerating voltage which is usually easy to regulate because of the low current drain which results in a constant small load. The plate voltage supply for the receiver and the indicator sweep circuits require a source of good regulation and very little ripple. Voltages are also required for relays, blower motors, antenna control motors, etc.

Combinations of vacuum tubes, transistors, rectifiers, vibrators, transformers, voltage dividers, etc., are used to provide these different voltages.

Power supplies of various types occur throughout the radar system because it is impractical to install all of them in a central location. Even though in some equipments the power supply may lose its identity as a separate unit, the function is still performed and must be tested and maintained at its rated performance.

Intermittent Troubles

Intermittent troubles are probably the most aggravating and irritating problem faced by the technician. The equipment always seems to be in proper operation while under observation, only to malfunction as soon as the technician turns his back. There is no single method for resolving this difficulty. The procedure to be used depends on the individual situation—the technician, the equipment, the available information, the peculiarities of the installation, etc. A thorough knowledge of the operation of the equipment, and an understanding of the most common causes of intermittent troubles should help to alleviate the suffering of the maintenanceman.

Some of the most common causes of intermittent troubles are loose vacuum tube elements, poor electrical connections, poor solder joints, leaky capacitors, arcing, broken terminal boards or printed circuit boards, fused conducting strips, and mechanical vibration. Vibration is usually associated with one or more of the others listed, either as a basic cause or as a contributing factor; therefore it should always be investigated early in the troubleshooting procedure. If the equipment seems to operate properly after a visual inspection fails to reveal the cause of the intermittent trouble, vibrate the equipment by tapping or jiggling while watching for indications of arcing, etc. If this fails to produce meaningful indications, methodical and patient troubleshooting procedures must be followed.

SPECIAL AVIONICS SUPPORT EQUIPMENT

The numerous and complex operations required for servicing and maintaining electronic equipment requires in some instances numerous classes of support equipment. Therefore, a test set or system that combines the function of several test sets, is practical and desirable. Support equipment has been developed that can be used to maintain or test complete systems in various types of aircraft. Two of these systems are known as Semi-Automatic Checkout Equipment (SACE) and Versatile Avionics Shop Test (VAST).

SACE

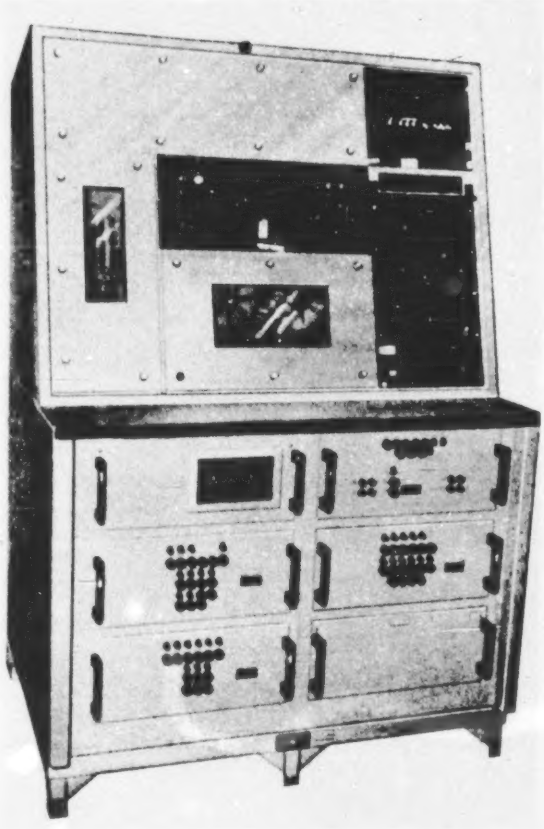
Responsibility for quickly getting the aircraft "up" and available rests, first of all, at the Organizational maintenance level. The aircraft is repaired at the Organizational maintenance level by locating and replacing the defective aircraft replaceable assembly (ARA).

The defective ARA is taken through supply to an Intermediate level shop which has the responsibility for repairing and/or adjusting the ARA and returning it to supply as a ready for issue (RFI) item. If the defective ARA belongs to the group of equipments which do not lend themselves to automatic testing, it will be "substituted" into a test-bench harness and analyzed down to the module and/or component level by using conventional test equipment. However, if the defective ARA belongs to one of the equipments or systems which can be checked with SACE, it will be connected to the corresponding SACE adapter console and automatically fault isolated to the module level. When defective modules are located, they are immediately replaced and the ARA is ready for service.

The defective module moves to the module repair area where it is fault isolated to the component level with a special test set. The special test sets are not computer controlled and are, therefore, not part of SACE.

SACE Shop

The operation of a SACE shop is controlled by a programer comparator (fig. 6-16). After the technician has connected the defective ARA to the appropriate SACE adapter test console (which, in turn, is connected to the programer comparator), he selects the correct programer comparator tape and inserts it into the pro-



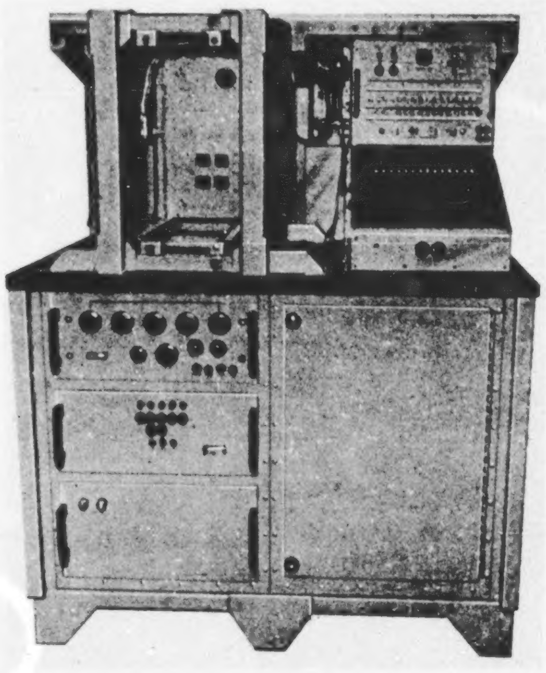
AQ. 632
Figure 6-16.—Programer comparator.

gramer comparator. He then presses the start button and the testing begins. The tests, performed automatically and continuously by the test console, will stop only for special instructions or when a defective module is located.

Programer analyzer test consoles are provided to test the programer comparator. Figure 6-17 displays a programer analyzer test console.

VAST

Versatile Avionics Shop Test (VAST) is the Navy's newest attempt to improve avionics maintenance and quicken turnaround time for avionics black boxes.



AQ. 633
Figure 6-17.—Programer analyzer console.

The VAST system, officially designated the AN/USM-247, will be installed in attack aircraft carriers (CVA) and at major shore installations. VAST will be able to handle the testing and troubleshooting of 85 percent of the Navy's future avionic systems; the remainder, involving such items as inertial and hydraulic devices and radiating portions of radar and infrared systems, will still require special test facilities.

Where circumstances do not readily permit each weapon replaceable assembly (WRA) to be designed to be directly compatible with VAST, interface transformation units may be approved. In its simplest form, an interface transformation unit (ITU) may be merely a test cable which adapts the VAST connector to the assembly connector. More complex ITU's may require passive elements, active elements, and even programable circuitry.

Avionic contractors must develop three types of test programs for each assembly which are compatible with the AN/USM-247. These include the following:

1. Overall (end to end) test, to determine whether an assembly (WRA) is operating properly.

2. Module isolation test, to enable a fault to be traced to a replaceable module within the assembly.

3. Fault isolation test, to permit malfunction to be traced to lowest repairable level within a module.

The avionic contractor's first step in preparing the software for use by VAST will be to prepare a diagnostic flow chart. Next, diagrams, showing which of the available VAST building blocks are necessary for each test and the interface transformation requirements, must be prepared. The test diagrams must contain special instructions for mode of operation, floating ground points, shielding, test points, pin connections, and functional input/output requirements.

Finally, the avionic contractor must write an English language program (ELP) on special forms. This lists such things as a functional description of each test, the stimulus level with acceptable tolerance, the allowable limits for satisfactory performance, and the next test to be performed, depending upon the results of the current test.

This contractor written ELP is then sent to a VAST programing center for conversion into the VTRAN language used by VAST.

VAST is designed for use with a general purpose digital computer. A single computer can serve as many as six individual test stations simultaneously on a time-share basis. Normally, only three stations will share a single computer to enable each to operate as if it were the sole computer user.

VAST can operate in an automatic mode, in which the computer runs through a sequence of tests rapidly and stops only when it finds a malfunction; or, it can be operated in a manual mode in which the human operator selects the test to be conducted if he has a clue as to the nature of the fault.

VAST is also designed to perform self-test operations to check that all units are operational. If it detects a malfunction, VAST is able to isolate the malfunction to one of its basic building blocks and then trace the fault to the defective module.

CHAPTER 7

AIRBORNE COMPUTERS

A computer is a device that performs mathematical calculations on input data to yield new and generally more useful results. The first computer, an abacus, was used by the ancient Greeks and Romans. It is a simple kind of manually operated device utilizing sliding beads; if operated according to definite rules, it can perform addition and subtraction very rapidly. Computers found in use today range from the mechanical adding machine and slide rule to room-sized complex devices.

Automatic computers are becoming increasingly common as a part of the electronic installations in naval aircraft. Present and future technicians will be faced with a collection of electronic equipments which use computers as integral portions of the overall system. To understand the operation of the system in general, and the computer portion in particular, it is necessary to have a basic understanding of computer functions, circuitry, terminology, and applications.

Digital Computer Basics, NavTra 10088-A, presents a basic coverage of the fundamentals of electronic data processing. In addition, chapter 15 of Basic Machines, NavPers 10624-A, presents coverage of some of the basic computer mechanisms in use. Review and study of these basic coverages will aid in understanding the material covered in this chapter.

COMPUTER CLASSIFICATION

The main division between computers is whether they be either digital or analog. However, they may be classified further by considering their construction as follows:

1. Electronic
2. Electromechanical
3. Mechanical

Electronic computers utilize electrical units, such as voltage amplitude and phase, resistance, electrical impulses, and other electrical units to represent physical quantities. Computers of this type usually contain electronic and magnetic amplifiers, phase detectors, modulators, and demodulators.

Electromechanical computers represent numbers or variables in both electrical and mechanical units. A typical application may employ both electrical and mechanical inputs to a servomechanism and may have a mechanical output.

Mechanical computers utilize mechanical quantities to represent the input and output values. They normally contain devices that add, subtract, multiply, or divide by means of gear ratios, shaft rotations, etc.

Many equipments are combinations of both the analog and digital types. This combination is called a hybrid computer.

A SPECIAL PURPOSE computer is one designed for a specific type calculation, such as navigation. A simple computer may be able to calculate ground track (ground velocity and direction). By proper selection and interconnection of units, it is possible to have a computer that will indicate the present position of an aircraft, course and distance to a preselected target, course and distance to home, estimated time of arrival at either or both, and whether sufficient fuel is available for the flight. As the problems become more and more complicated, so does the overall equipment. However, even the most complex equipment is made up of many relatively simple components.

By increasing the number of computing units and making the interconnection of these units sufficiently flexible, the computer may be used to perform almost any type computation. A computer of this type is called a GENERAL PURPOSE computer. There are very few general purpose analog computers, most general purpose computers being digital. Because of the necessary complexity, general purpose computers are too large and heavy for airborne use; their use is normally limited to shorebased activities, or to the larger ships. Nearly all airborne computers are of the special purpose type.

APPLICATION

Computers in use today are performing many functions, among which are the following:

1. Solving design problems of many different types.
2. Solving problems in personnel, fiscal, and stock control management.
3. Processing information from missile ranges and tracking stations.
4. Automating processes.
5. Training by simulation.
6. Forming a part of complex military systems and operations on land, at sea, and in the air.

As a part of naval aircraft systems, computers are used in connection with AEW (Airborne Early Warning), ECM (Electronic Countermeasures), ASW (Antisubmarine Warfare) attack, reconnaissance, intercept, and command missions. They perform such functions as communications link and relay, navigation, fire control, tracking, strategy, tactics, logistics, selection and identification of targets, etc. It is obvious that computers, with such wide and diverse usage, form a considerable part of the technical responsibility of the AT as well as personnel from other ratings.

Analog computers are best employed where continually varying solutions are needed for problems whose factors are continuously varying. These factors generally are physical quantities, such as velocity, direction, or range. Such physical quantities are most conveniently represented by degrees of shaft rotation, magnitude or phase of a voltage, or the speed and direction of movement of some mechanical part. The varying instantaneous summation, or simultaneous solution, of outputs from all the computing parts comprises the computer's output.

Different physical systems can often be described by the same mathematical equation. When you talk about a specific physical system, it is important to define exactly what system you are discussing; this is where mathematics is used. Mathematics' precise nature makes it ideal for describing physical systems. Often, this mathematical description applies to more than one physical system. Systems which are described by the same mathematical model (description) are called analogous systems. The remainder of this chapter will cover the mathematics used to describe a physical system and the physical systems used to solve mathematical equations (analog computation).

ANALOG COMPUTATION PRINCIPLES

There are a number of requirements which an airborne analog computer must fulfill. Primarily, it must possess sufficient accuracy to solve a problem within the required limits. It must be constructed in a manner whereby it can withstand the stresses of airborne use and require a minimum of maintenance. It is also advantageous from the maintenance standpoint for a computer to use as many similar components as practicable, keeping the number of spare parts to a minimum. This requires the rearrangement of equations from their simplest form to one that is more complicated for reasons not readily apparent to the technician. Many computers have been designed around equation rearrangement.

EQUATION REARRANGEMENT.

The equation below represents a typical problem to be solved within a computer.

$$J = \frac{Rt_f}{R_f}$$

The factor J is a mathematical quantity determined by the factors R (present range of airborne target), t_f (time of flight), and R_f (future range of the target). The quantity J has no significant meaning other than that it represents the term $\frac{Rt_f}{R_f}$ in the above equation. One method of solving this problem requires the use of a servosystem.

As should be recalled, the operation of a servomechanism is dependent upon its ability to compare two quantities and feed an error signal to its output device, which, in turn, causes the error signal to be canceled. The servosystem may be utilized to give a continuous solution to the problem if the formula is rearranged to give a zero output. By multiplying both sides of the above equation by $\frac{R_f}{Jt_f}$ and transposing, the equation can be written as follows:

$$\frac{R}{J} - \frac{R_f}{t_f} = 0$$

Another example of equation rearrangement involves the use of logarithms. A computer problem may involve the multiplication and division of several quantities. Referring again to the equation

$$J = \frac{Rt_f}{R_f}$$

it can be arranged as follows:

$$\log_{10} J = \log_{10} R + \log_{10} t_f - \log_{10} R_f$$

The logarithm of each quantity may be found electronically by the use of specially designed networks. (These networks are discussed later in this chapter.) When the equation has been changed into the logarithmic form, the computing is accomplished by simplified addition and subtraction of the quantities. Magnetic amplifiers are especially well suited for solutions of this type.

The results of logarithmic computation frequently can be used in the logarithmic form. However, the antilogarithm may also be found by use of a network giving an answer to the problem in the same form in which it was originally stated.

IMPLICIT SOLUTION

The use of computers to solve complex problems does not always afford direct solution to all parts of the problem. Thus, the solution may be based on indirect or implicit methods.

Implicit problem solving may accomplish subtraction by means of addition, division by means of multiplication, the extraction of a square root by means of squaring, and differentiation by means of integration. The following is a comparison of explicit and implicit methods of problem solving:

	EXPLICIT	IMPLICIT
Subtraction	$c = a - b$	$c + b = a$
Square root	$c = \sqrt{a}$	$c^2 = a$
Division	$c = a/b$	$cb = a$

The use of the implicit function technique is found frequently in airborne computers. There are numerous computations for which the implicit method may be more accurate or more convenient, based on the information available to the computer. Servomechanisms and amplifiers utilizing negative and positive feedback are well suited for instrumentation of implicit operations.

QUANTITY REPRESENTATION

For the purpose of this chapter, representation of quantity may be defined as that physical quantity used by an analog computer to represent a specific input quantity. Thus, for example, a specific quantity (range from an aircraft to a specific tacan beacon) may be identified with a d-c voltage fed to the analog computer for solution of the problem.

IDENTITY OPERATIONS

For the purpose of this discussion, an identity operation may be defined as any operation that does not change the mathematical quantity represented. Examples of identity operations are changes in scale factor, voltage level, impedance, and data representation.

Change in Scale Factor

Before discussing a change of scale factor, let us first define scale factor. In an analog computer, the scale factor is the ratio of the analog unit to the equation unit. Thus,

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units (physical)}}$$

Any change in analog units without a corresponding change in equation units will result in a change in scale factor. To illustrate this, consider the following example:

A 10-volt positive d-c signal is selected to represent a range of 1,000 yards.

$$\text{scale factor} = \frac{+10 \text{ volts}}{1{,}000 \text{ yards}}$$

$$= 0.01 \text{ volt per yard}$$

If the 10-volt signal is fed through a d-c amplifier having a voltage gain of 10, the analog unit is now equal to 100 volts. The scale factor is:

$$\text{scale factor} = \frac{+100 \text{ volts}}{1{,}000 \text{ yards}}$$

$$= 0.1 \text{ volt per yard}$$

Thus, the scale factor was changed by the action of the amplifier.

When the multiplier is less than one, simple networks of resistance, capacitance, or inductance may be used. When the constant of multiplication is greater than one, amplifiers whose gain has been accurately calibrated may be used.

Change of Voltage Level

Computers, such as those utilizing addition and subtraction, must frequently change or shift the voltage level or reference to that level usable by subsequent components or units. A possible example of a shift in voltage level is found in direct-coupled amplifiers where the equipment is limited by the output of the d-c supply for the amplifier.

Change of Impedance

A change in output impedance may be required to match the various sections of a computer. This may be accomplished by the use of networks, and in some cases the use of cathode followers or other amplifiers employing feedback.

LINEAR FUNCTIONS

A linear function in mathematics is one that can be shown by a straight line on rectangular graph paper. Linear functions include those functions that involve summation (addition and subtraction), multiplication, and division, but not those that involve squares, square roots, trigonometric functions, and logarithms.

SUMMATION

The process of summation can be accomplished with electrical, mechanical, or electromechanical devices. Voltages are added, motions are added, or voltages and motions may be combined to give an output proportional to their inputs.

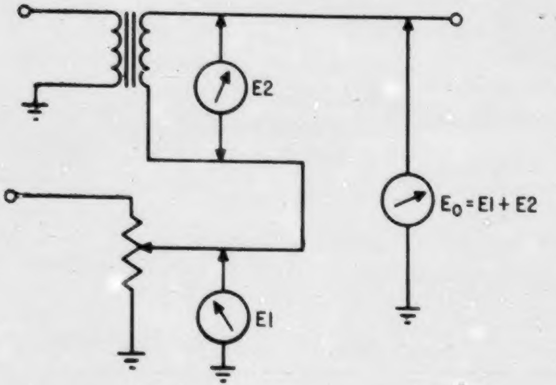
Electrical Summation

To simplify the presentation, both electrical and electronic summing devices will be discussed under this heading. The first device will be the series circuit in which the output voltage E_o is simply the series addition of the input voltages E1 and E2.

$$E_o = E1 + E2 \qquad (1)$$

Only one of the input voltages can be grounded. Any others must be isolated from ground. This is illustrated in figure 7-1. Note that the secondary of the transformer is ungrounded, while the voltage E1 is from a grounded source. Isolating transformers must be carefully designed to minimize capacitive coupling from primary to secondary winding, which would cause phase shift variations.

Series adding is primarily used when voltage sources are inductive units, such as synchros,



AQ. 495

Figure 7-1.—Series addition.

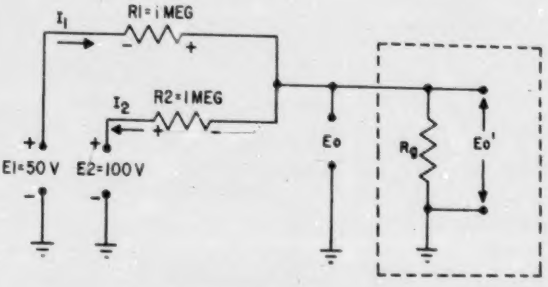
tachometers, resolvers, etc., already isolated from ground. Series summation is also used when the attenuation of parallel summation networks cannot be tolerated.

When subtracting two a-c voltages by this method, they should be 180° out of phase for correct results. Combining voltages that are not in phase or 180° out of phase results in a quadrature voltage and consequently an error in the output.

If d-c voltages are to be added in series, transformers cannot be used and a separate d-c power supply is required for each term or input to obtain isolated sources of voltage.

It should be remembered that the methods presented in this chapter are basic, and many variations of these methods will be found in equipments.

A parallel resistance network can also be used to electrically produce the algebraic sum of several input voltages. Voltages E1 and E2 are connected in series with two resistors R1 and R2 and terminated at a common junction as shown in figure 7-2. The voltage E_0 is not the actual sum of the input voltages, but is proportional to that sum.



AQ. 496

Figure 7-2.—Parallel summation network.

Using the values given in figure 7-2, it can now be proved that the output voltage E_o is proportional to the inputs. If the voltage E_o feeds into an infinite impedance, there is no load current. The circuit may now be considered as a series circuit, with

$$I1 = I2 \tag{2}$$

Then, since all branches are parallel,

$$E1 + I1R1 = E2 - I2R2 = E_o \tag{3}$$

Solving the currents in each part of equation (3) and substituting the results into equation (2),

$$\frac{E_o - E1}{R1} - \frac{E2 - E_o}{R2} = 0 \tag{4}$$

Solving equation (4) for E_o,

$$E_o = \frac{\frac{E1}{R1} + \frac{E2}{R2}}{\frac{1}{R1} + \frac{1}{R2}} \tag{5}$$

or, by further simplification,

$$E_o = \frac{R2E1 + R1E2}{R2 + R1} \tag{6}$$

Thus, an expression for voltage E_o has been obtained in terms of the sum of the two input voltages and their respective series resistors.

The voltage E_o was obtained above by assuming a very high-impedance load. If a grid resistor R_g is included, the voltage E_o is determined by:

$$E'_o = E_o \times \frac{R_g}{\frac{R1R2}{R1 + R2} + R_g}$$

As pointed out previously, the voltage output is not the actual sum of the input voltages, but is proportional to that sum. The following example illustrates this proportionality:

E1 = 50 volts	E2 = 100 volts
R1 = 1 megohm	R2 = 1 megohm

Then, using equation (5),

$$E_o = \frac{\frac{50}{1 \times 10^6} + \frac{100}{1 \times 10^6}}{\frac{1}{1 \times 10^6} + \frac{1}{1 \times 10^6}}$$

$$E_o = \frac{150}{2} = 75 \text{ volts}$$

If E_o were the actual sum of the input voltages, the voltage output would be 150 volts. However, this difference in actual sum and proportional voltage can be compensated for by a change in scale factor.

When a difference between two terms is required (subtracted), a negative voltage is used to represent the quantity being subtracted (the subtrahend). Both the negative and positive voltages are fed to the parallel resistance network as previously discussed.

Scale Factor

Although addition has been explained as a summation of voltages, the computer's real job is to add physical units, such as feet per second or degrees per minute. The proper application of scale factors makes the addition of physical units of an equation possible. The following transformation formula is used for this purpose:

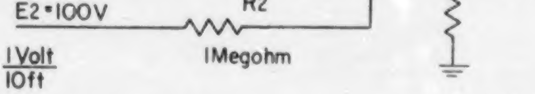
Equation units × scale factor = analog units

When the physical inputs to the analog computer are represented by voltages, the final solution in the proper units can be found only by dividing the summed voltages by the output scale factor. If the voltage E1 and E2 in figure 7-3 were chosen to represent 1,000 feet each, the scale factor for the input voltages would be 1 volt per 10 feet and should be written as 1 volt/10 feet.

If the output physical units are to equal the sum of the input physical units, the scale factor at the output must be 1 volt/20 feet. By using the transformation formula, the sum of the physical units is obtained as follows:

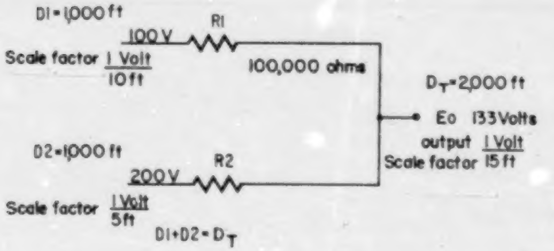
$$2{,}000 \text{ feet} \times \frac{1 \text{ volt}}{20 \text{ feet}} = 100 \text{ volts}$$

In the examples discussed previously, the input scale factors were identical. Consider the operation of the summing circuit shown in figure 7-4 if the input scale factors are different.



AQ. 497

Figure 7-3.—Scale factors assigned to parallel resistor summation networks.



AQ. 498

Figure 7-4.—Addition with unequal scale factors.

In the equation, $D_t = D1 + D2$, D1 has a scale factor of 1 volt/10 feet and D2 is represented by the scale factor 1 volt/5 feet. Since the physical units per volt of the scale factors must add directly, the output scale factor is 1 volt/15 feet. This result is obtained by thinking in terms of units per volt (reciprocal of scale factor) for the addition operation. Direct addition of the scale factors for D1 and D2 would not result in the desired addition of physical units, because the scale factor definition places the physical units in the denominator.

From the example in figure 7-4, the correct answer for D_t is 2,000 feet. What values of R1 and R2 will supply the answer if the analog unit at the output is known and the output scale factor is known? The analog unit is obtained by substituting in the following formula:

$$\text{analog unit} = \text{equation unit} \times \text{scale factor}$$

$$= 2{,}000 \text{ feet} \times \frac{1 \text{ volt}}{15 \text{ feet}}$$

$$= 133 \text{ volts}$$

Referring to equation (6), it is apparent that R1 cannot equal R2 as in the previous example. It is permissible to select one resistance value arbitrarily; consequently R1 may be set equal to 100,000 ohms, a typical value. Substituting known values in equation (6) and solving for R2:

$$133 = \frac{(R2 \times 100) + (100{,}000 \times 200)}{100{,}000 + R2}$$

$$R2 = 200{,}000 \text{ ohms (approximate)}$$

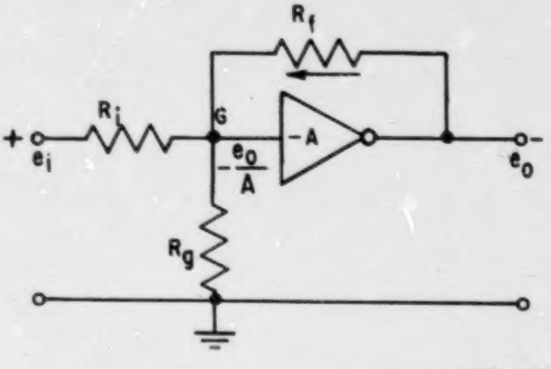
The Aviation Electronics Technician will not be expected to compute component sizes or scale factors. However, it is of the utmost importance that he have a thorough understanding of scale factors in order that he may understand what is being accomplished in each stage of a computer and also how it is being accomplished.

Electronic Amplifiers Used for Isolation

In analog computers it is not always possible to apply the output of parallel resistor summation networks directly to subsequent circuits without getting nonlinear results because of loading. Loading is avoided by using an isolation amplifier with a high-impedance input and a low-impedance output between the summation network output and the succeeding computer component.

Since the signal magnitude is the computed quantity, the gain of these isolation amplifiers must necessarily be quite accurately maintained. The gain of any amplifier, of course, is affected by such things as a weak tube, a shift in power supply voltage, temperature changes, etc. The proper use of negative feedback is quite effective in solving this problem. Since a large amount of negative feedback is required if the full advantage of feedback stabilization is to be obtained, high-gain amplifiers are needed in such circuits. The gain of the amplifier itself does not affect the overall circuit gain because of the negative feedback. Figure 7-5 shows the basic circuit employing an isolation amplifier.

The amplifier output is fed back to the summing point G at the input of the amplifier through the feedback resistance R_f. Since the gain of the amplifier is extremely high, the voltage $-e_o/A$ at the summing point G is very nearly zero. (Recall that the value of any fraction whose denominator is extremely large approaches zero very closely.) Thus, the current through R_g is negligible. Assuming the amplifier input does not draw current (normally a very good assumption) and that the amplifier gain is high (that is, $1/A$ is much less than 1), the current through R_i equals that through R_f (negative direction), by Kirchhoff's current law at point G, or:



AQ. 499

Figure 7-5.–Basic isolation amplifier circuit.

$$\frac{e_i}{R_i} = \frac{e_o}{-R_f}$$

Rearranging, to obtain an expression for gain:

$$\frac{e_o}{e_i} = \frac{-R_f}{R_i}$$

This is the basic equation which describes the operation of any circuit utilizing a high-gain amplifier with negative feedback. It is well worth remembering.

Thus, if $R_i = R_f$, the circuit gain is unity, and the circuit is quite effective as a precision isolation device. The loading which this circuit presents to its driving circuit is essentially R_i, since the voltage at point G is essentially zero.

If the amplifier gain deteriorates with age, there is some point at which the approximate expression for circuit gain no longer holds. A more exact expression which shows the effect of amplifier gain is

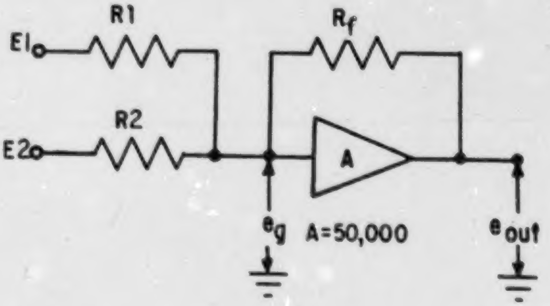
$$\frac{e_o}{e_i} = \frac{-R_f}{R_i}\left(\frac{A}{1 + A}\right)$$

This equation may be used to show that even if the amplifier gain is designed to be only 100, a reduction in gain to about 50 percent is required to reduce the circuit gain by 1 percent.

SUMMING AMPLIFIERS.–The high-gain d-c amplifiers described in the foregoing discussion are used in many applications where their isolation characteristics are needed. Typical of such application is their use in summing circuits where loading effects are serious. When used in this way, they are connected as shown in figure 7-6. The entire circuit, including the electrical summing network, the high-gain amplifier, and the feedback loop, is called a "summing amplifier."

Recall that the overall gain of the feedback amplifier circuit is determined by the ratio of feedback impedance to the total input impedance. When this ratio is 1 (both impedances equal), the gain of the amplifier circuit is unity and the circuit merely algebraically adds all the input voltages.

Practically speaking, the number of inputs to a summing amplifier are limited by amplifier saturation. A typical summing amplifier has an input voltage range from −50 to +50 volts and an output voltage range from −100 volts to +100 volts. This means that the total input voltage cannot exceed ±50 volts, and that the individual voltage inputs and gains must be such as to provide a total output that does not exceed ±100 volts. When these conditions are exceeded,



AQ. 500

Figure 7-6.–Summing amplifier schematic.

amplifier saturation occurs and further linear amplification is impossible.

OPERATIONAL AMPLIFIERS.—By now it should be clear that almost any mathematical operation can be performed by suitable mechanical and electronic devices. Some of these operations have already been discussed. Others, including the calculus operations of differentiation and integration, will be discussed later in this chapter.

The use of high-gain d-c amplifiers has become commonplace in the performance of these operations; hence the term "operational amplifiers." This term will be used throughout the remainder of this chapter in a general sense, signifying any high-gain d-c amplifier which employs negative feedback.

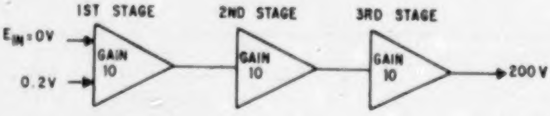
Up to this point, we have assumed that the d-c amplifiers used in operational amplifiers can produce an output voltage that is an exact magnified version of the input voltage, but exactly 180° out of phase with the input. For a number of reasons, practical amplifiers fail to perform in this ideal manner.

The first reason is based upon the fact that the usual operational amplifier consists of three cascaded d-c amplifier stages with a combined open loop gain of 50,000, or 92 db. The closed loop gain (that is, the gain obtained when a feedback resistor that is equal in value to the input resistance is connected between the output plate and the input grid) is unity.

At the high gains used in these amplifiers, any spurious voltage variations that occur in the d-c amplifier stages may produce a considerable amount of undesired variation or drift in the amplifier output voltage. Drift shows up as a voltage imbalance that appears at the amplifier output terminals in addition to the correct output voltage. When it occurs in computer applications, this imbalance produces errors in the computation.

There are four main causes of drift. They are:

1. Power supply voltage variation.
2. Filament voltage variation or transistor bias variation.
3. Varying resistance values.
4. Varying vacuum tube characteristics or transistor parameters.



AQ. 501

Figure 7-7.—Gain in three stages of amplification.

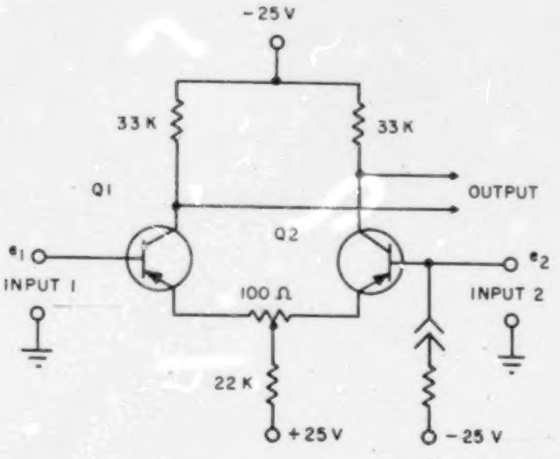
Other operational amplifier errors are caused by seemingly insignificant currents and voltages such as leakage currents, voltage drops in ground loops, and grid currents. The resulting currents are in the order of fractions of a microampere. Yet, these currents flow through the input resistors. A current of 0.1 microampere flowing through a 1-megohm resistor will generate an error voltage of 0.1 volt.

As shown in figure 7-7, if an assumed 0.2-volt grid-voltage change is produced by a filament-voltage change, an output voltage change of 200 volts is obtained even though the input signal voltage is zero. By means of a similar analysis it is possible to show that plate or collector supply voltage changes and cathode or emitter emission variations would all tend to increase the output voltage imbalance, and that they would produce the most serious effects when they occur in the first stage.

Changes in transistor parameters, due to temperature variation, are the main cause of drift in transistorized d-c amplifiers. The most widely used drift reduction circuit is the differential amplifier (fig. 7-8). As the name implies, the output voltage (taken between collectors) is equal to the difference between the two input voltages. Any output variations caused by drift voltages are canceled because both transistors are almost equally affected and the difference voltage between collectors remains constant.

The circuit can be used either with two inputs or with one having a fixed bias. In either case, collector current drawn by one transistor affects that drawn by the other because of the common emitter resistor.

An increase in the collector current of transistor Q1, for example, increases the emitter voltage of transistor Q2. However, the base-to-



AQ. 502

Figure 7-8.—Basic differential amplifier.

emitter voltage of transistor Q2 will be decreased (if the base voltage is held constant). since the difference between the base voltage and emitter voltage appears there. Consequently, the base current of transistor Q2 decreases and the collector voltage increases. Since the collector voltage of transistor Q1 decreases, the difference voltage becomes greater.

The differential amplifier provides a gain determined by the current gain of each stage. As one collector voltage is reduced, the other collector voltage is increased. The difference between the two collectors is much greater than the difference between the two input voltages because of the current gain of the two transistors. The high value of emitter resistance and voltage also provides a very high input impedance.

The potentiometer in the emitter circuit is used to adjust the circuit output voltage when no input is present; that is, by varying the emitter voltages of the two transistors, it is possible to select the values of quiescent base currents.

As previously mentioned, most operational amplifiers consist of a basic 3-stage d-c amplifier. The reason for using multiple stages is the need of obtaining high gain; the reason for using an odd number of stages is that we can thus obtain the required reversal of polarity between the input and output voltages. (Recall that negative feedback is used in the operational amplifier.)

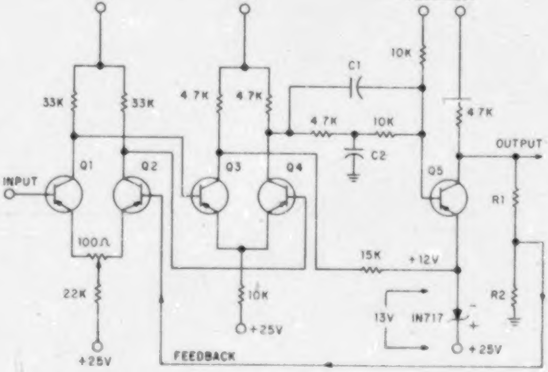
Figure 7-9 shows a 3-stage d-c amplifier schematic which consists of two differential amplifiers and a conventional amplifier. Negative feedback is used within the amplifier to provide stable gains over a wide range of frequencies.

In negative feedback circuits, a fixed portion of the output voltage is fed back to the input and used to cancel out a portion of the input voltage or current. In some ways the feedback circuit consisting of R1 and R2 appears similar to the collector-to-base negative feedback.

To function properly, the feedback and the output voltage of the overall amplifier must be exactly in phase with the input voltage and current.

Unfortunately, however, the input capacitances of each stage introduce time delays or phase shifts. These phase shifts depend upon the frequency components of the signal passing through the amplifier. Without some form of compensation, distortion would be produced as a result of subtracting two current waveforms that are not exactly in phase.

The resistor capacitor network applying base



AQ. 503

Figure 7-9.—A three-stage d-c amplifier.

current to transistor Q5 provides the extra phase shift required to make the output voltage exactly in phase with the input voltage and current.

Electromechanical Summation

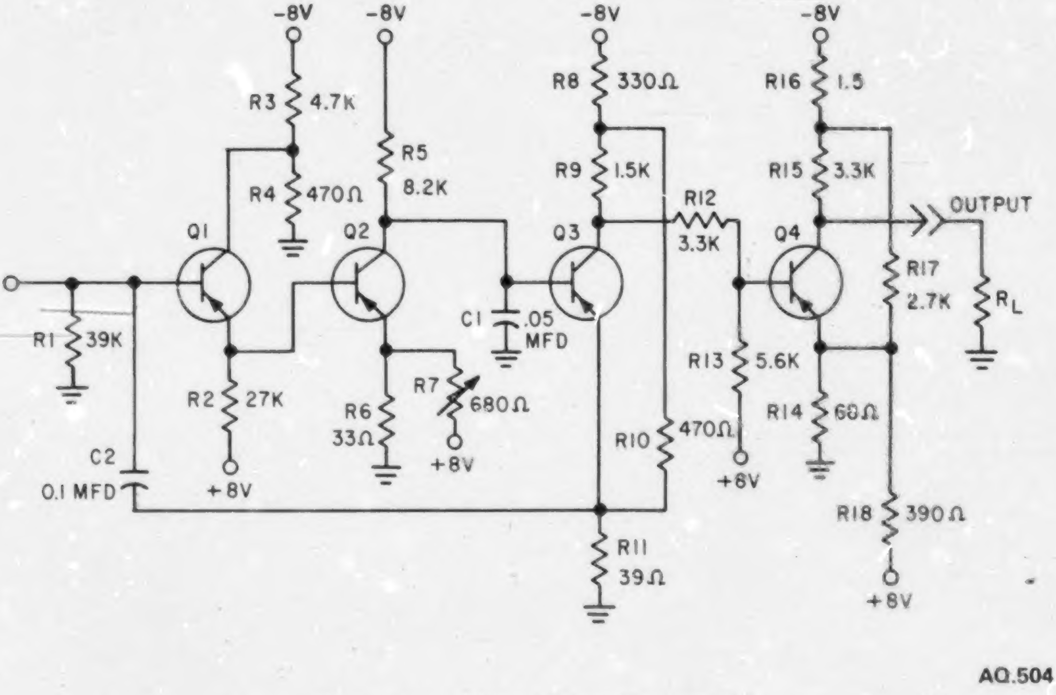
If the inputs or outputs of a summing operation cannot be physically brought together, a synchro system may be used. A chain of three synchro units consisting of a synchro transmitter, a synchro differential transmitter, and a synchro receiver adds or subtracts shaft rotations. If an output voltage rather than a shaft rotation is needed, the synchro receiver can be replaced with a synchro control transformer. Gear ratios may be added between the input shaft and the differential transmitter rotor to introduce coefficients. An example formula might be as follows:

$$\theta_o = \theta 1 \pm K \theta 2$$

The accuracy of a synchro summing system may be increased by using a two-speed synchro transmission system, as described in chapter 3 of Synchro, Servo and Gyro Fundamentals, NavPers 10105.

MULTIPLICATION

Multiplication is one of the mathematical operations which must be performed in a computer. It may be performed electronically by transistor amplifiers, electron tube amplifiers, or by magnetic amplifiers, electromechanically by potentiometers, and mechanically by devices called multipliers.


-8V
-8V
-8V
-8V
R3
4.7K
R4
470Ω
R5
8.2K
R8
330Ω
R9
1.5K
R16
1.5
R15
3.3K
R12
3.3K
OUTPUT
Q1
Q2
Q3
Q4
R1
39K
C1
.05
MFD
R17
2.7K
R$_L$
R13
5.6K
R2
27K
R7
680Ω
R6
33Ω
R14
68Ω
R10
470Ω
C2
0.1 MFD
+8V
+8V
+8V
R18
390Ω
R11
39Ω
+8V

AQ.504

Figure 7-10.—A high gain operational amplifier.

Electronic Methods

Every linear amplifier is a multiplier. The d-c amplifier previously discussed had a voltage gain of 100. Now, a high gain operational amplifier with a gain of 25,000 will be discussed. The complete high gain operational amplifier is shown in figure 7-10. The maximum allowable output voltage is ±5 volts. Since the circuit voltage gain is 25,000, the input signal should not exceed ±0.0002 volt (0.2 millivolt).

When the amplifier is used as an operational amplifier, the following restrictions are observed:

1. The gain with feedback should never produce an output greater than 5 volts.
2. The input resistor should be small compared with the input resistance of the operational amplifier. This limits the value to about 5K (one-tenth of the input resistance). The feedback resistor can be any desired value.
3. The input resistance of the following stage must be 1500 ohms or more.

The input stage (fig. 7-10) is composed of transistor Q1 and is a grounded collector amplifier (emitter/follower). The voltage divider in the collector circuit provides a small negative voltage for the collector of the transistor. This voltage, approximately −0.8 volt, allows the output of the stage to assume small negative values. The input voltage varies from zero to plus or minus 0.0002 volt. As a result, the output voltage of the first stage is in this range.

The second stage (fig. 7-10) consists of transistor Q2, which is a common emitter amplifier. The 33-ohm resistor in the emitter circuit develops the bias voltage for the stage; that is, the voltage divider network causes the emitter junction to be positive with respect to the base. This results in the flow of a small bias current. Also, the 33-ohm resistor causes a negative feedback to occur in the second stage. Although this feedback reduces stage gain, it also provides wide frequency response and reduces noise, drift, and other undesirable effects.

Transistors Q3 and Q4 (fig. 7-10) form the third stage and the output stage and both are high gain, common emitter amplifiers. Emitter resistors are used to provide self-bias. Positive feedback is used in these stages to offset the negative feedback introduced by the emitter resistors. The positive feedback is obtained by feeding a portion of the voltage developed across the collector resistors to the emitter. The emitter of the output stage also receives a bias voltage as a result of a series resistor connected to the positive voltage supply.

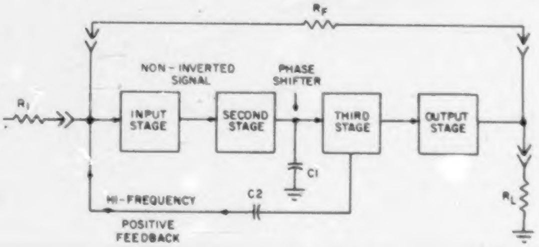


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Figure 7-11.—Block diagram of a high gain operational amplifier.

A block diagram of the high gain operational amplifier is shown in figure 7-11. This block diagram is displayed so that the feedback paths can be more readily seen. Note that a single capacitor C1 is used for phase shift correction. In additional, a special positive feedback path is provided for the higher frequency components of the input signal. Note also that the output of the third stage is in phase with the input because the input stage does not invert the signal.

External feedback resistors (R_f and R_1) are also shown. The gain, with feedback, can be varied from 1 (input resistor of 4.7K and feedback resistance of 4.7K) to 10 (input resistor of 4.7K and feedback resistance of 47K). Higher gains are obtained by using higher values of feedback resistance. In most analog computer applications, however, a gain of 10 is sufficient. Feedback in amplifiers is discussed in detail in Basic Electronics, Vol. 1, NavPers 10087-C.

Electron tube amplifiers are also capable of solving multiplication problems involving two variables as represented by the equation

$$e_o = kxy$$

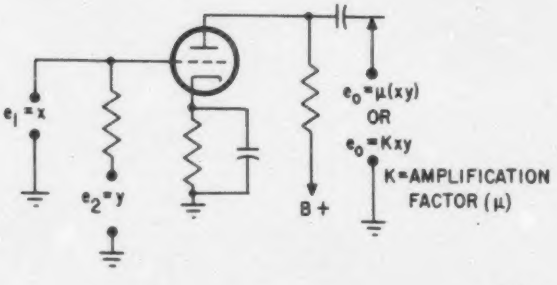

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Figure 7-12.—Variable gain tube as a multiplier.

Figure 7-12 illustrates a typical triode multiplication circuit. One variable input is applied as grid bias (preferably a d-c voltage) which establishes the gain of the stage. The other variable input is applied to the grid of the tube.

The output is a proportional quantity equal to the grid signal modified by the gain which is proportional to the variable bias voltage. This method is limited in scope and has limited accuracy due to variations in tube characteristics, contact potential, plate and filament supply changes, etc.

An improved multiplying circuit is shown in (A) of figure 7-13. Its operation is similar to the circuit shown in figure 7-12 except that it employs the use of two separate grids. The voltage gain of the stage is controlled by the voltage on grid 3 as shown by the curve illustrated in (B) of figure 7-13.

The gain of the amplifier is proportional to the voltage e_3 and may be expressed as follows:

$$A = ke_3$$

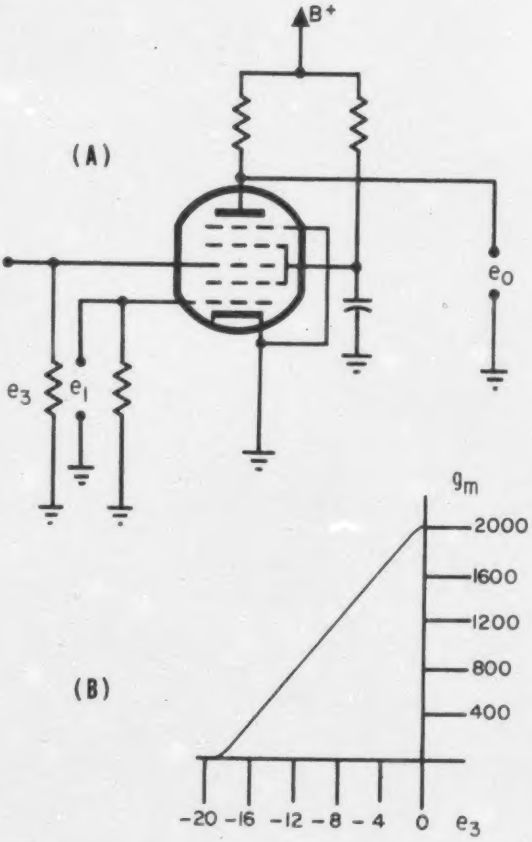
If the output voltage e_o is directly proportional to e_1, the input signal, then

$$e_o = Ae_1$$

Substituting for A, we have

$$e_o = ke_1 e_3$$

The output is a proportional quantity as indicated by the constant k.



AQ. 507

Figure 7-13.—A multielectrode tube used as a multiplier.

NOTE: It is common in discussions of amplification as related to computers to emphasize the fact that an odd number of amplifiers inverts the signal. This is interpreted mathematically by use of a negative sign and the symbol A (for amplification factor) and is often written as −A.

Magnetic amplifiers may also be used to multiply one factor by another. The saturable core reactor element in magnetic amplifiers makes the magnetic amplifier easily adapted for multiplying operations. Its amplification can be made proportional to a bias current over a limited range. However, accuracy is limited by variations in magnetic characteristics and winding resistance due to temperature variations.

Electromechanical Methods

Some of the electromechanical devices used for multiplication are potentiometers, synchros, and precision variable autotransformers (usually called by trade name, Variac).

Precision potentiometers are frequently used as multipliers in airborne avionics equipment because they are accurate, rugged, simply constructed, and inexpensive. They are equally well suited for a-c or d-c applications. Figure 7-14 illustrates a typical potentiometer type multiplier circuit.

The voltage occurring between the wiper and one end of the potentiometer is in reality the product of multiplying two quantities:

$$E_o = E_{in}\ \theta$$

One quantity is the voltage impressed across the resistor element, and the other is the position of a wiper. When E_{in} is 100 volts and θ is 100 percent, E_o is equal to 100 volts. If θ is 50 percent of full shaft rotation, E_o is equal to 50 volts. Such close correspondence can be achieved only if the potentiometer is precision device with linear resistance.

A grounded center tap on the potentiometer winding would permit either a positive or negative output, depending upon the polarity of the input voltage and the position of the wiper shaft. The potentiometer type multiplier actually multiplies a quantity by a factor of less than one. This presents no problem as the scale factor may be adjusted to give the desired output.

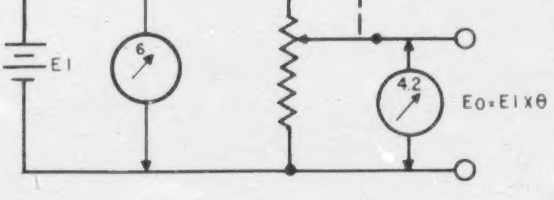


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Figure 7-14.–Potentiometer type multiplier circuit.

Autotransformer multiplication is identical with potentiometer multiplication except that the input voltage must be a.c. The input impedance of an autotransformer is high, and its regulation under load variations is very good due to the low d-c resistance of the winding.

The low output impedance of the variable autotransformer permits it to be connected directly to other transformers, potentiometers, or inductive resolvers, without intervening isolation amplifiers.

DIVISION

Instrumentation of division problems in an explicit form is generally difficult to perform. However, division can be accomplished by taking the reciprocal of the divisor and multiplying it by the dividend. This allows the use of less complex multiplication devices, a method normally found in aviation electronic equipments.

Electronic Dividers

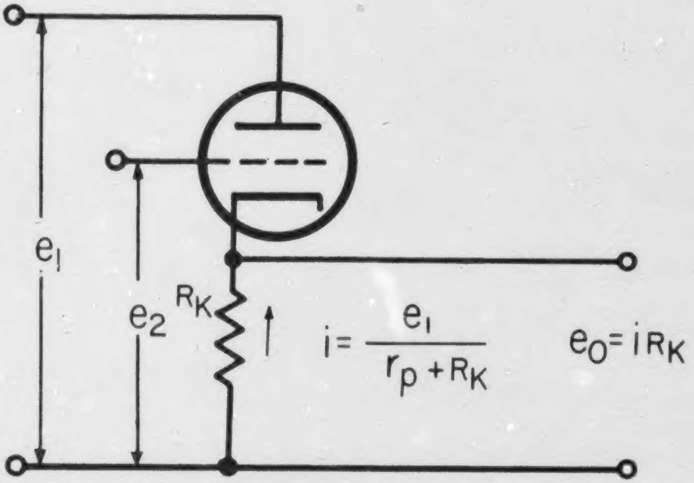
Electronic division can be performed by inserting a vacuum tube in place of the variable resistor in a rheostat divider network. The plate resistance of the tube is varied by the voltage applied to the control grid. Figure 7-15 illustrates the circuit of an electronic divider.

The cathode resistor performs the same function as R2 in figure 7-16. As in other electronic circuits, the circuit must be operated within limits determined by its components.

Electromechanical Dividers

A rheostat, or a potentiometer connected as a rheostat in a voltage divider circuit, provides a means of dividing a voltage by a shaft position. The voltage divider is an extremely simple method of dividing. The input voltage is applied to one end of the rheostat, and the second input is the shaft position of the rheostat. Figure 7-16 illustrates the operation of a divider network.

Since the shaft position of the movable contact controls the series resistance, current is a quotient of voltage divided by the circuit resistance. The quotient can be obtained as a voltage across the fixed resistor R2, in series with the rheostat. As in any analog system of division,



AQ. 509

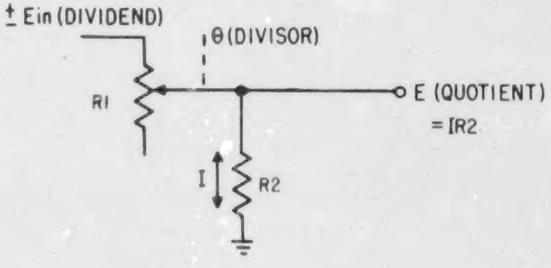
Figure 7-15.—Electronic divider circuit.

the divisor cannot go to zero since the quotient would then become infinity. R2 limits the current, and its value establishes the range of the divisor.

A voltage E_{in} is made proportional to one input and the resistance R1 + R2 is proportional to the second input.

The current

$$I = \frac{E_{in}}{R1 + R2}$$



AQ. 510

Figure 7-16.—Rheostat divider network.

The output voltage

$$E_o = \frac{E_{in}}{R1 + R2} \times R2$$

or

$$\frac{E_o}{R2} = \frac{E_{in}}{R1 + R2}$$

Substituting K for the constant value of R2, and θ for the variable R1:

$$\frac{E_o}{K} = \frac{E_{in}}{\theta + K}$$

The term K affects E_o only as a scale factor change. It affects θ only as a shift in value. Consider as an example the equation for determining angular velocity.

$$\omega = \frac{S}{D} \text{ radians per second}$$

Where S is linear velocity in feet per second and D is the slant range with limits from 600 to 6,000 feet.

The value of R2 represents the minimum range of 600 feet and R1 + R2 represents 6,000 feet.

$$\frac{R2}{R1 + R2} + \frac{600}{6{,}000} \text{ or } R1 = 9R2$$

A value for R2 is selected which will produce reasonable current limits over the range of E_{in}. If E_{in} has a range from +100 to −100 volts and the maximum current which may be drawn is 10 ma, R2 becomes 10,000 ohms. R1 will then vary from 0 to 90,000 ohms as D goes from 600 to 6,000 feet. E_o at maximum speed and minimum range will be as follows:

$$\frac{100 \times 10{,}000}{10{,}000} = 100 \text{ volts}$$

When D = 6,000 feet, maximum speed will produce an angular velocity output represented by an output voltage E_o of:

$$\frac{100 \times 10{,}000}{90{,}000 + 10{,}000} = 10 \text{ volts}$$

Since range cannot have a negative value, this method is only suitable when the divisor has the same polarity at all times.

Servomechanisms are often used for implicit division in computers. Division is usually represented by the equation

$$x = \frac{y}{z}$$

However, in order to utilize a servomechanism, the equation is rearranged as follows:

$$y - xz \text{ is } 0$$

The instrumentation of the equation is shown in figure 7-17.

The system has two electrical inputs, the amplitude and polarity of which are determined in other units. The voltage y is fed directly to the error detector while the voltage z is multiplied by the shaft position x, with the product xz being fed to the error detector for comparison with the input y. As in any servosystem, the error voltage drives the servomotor in the direction that will cancel the error voltage, given a zero output.

NONLINEAR FUNCTIONS

Under this heading, instrumentation of various mathematical operations, such as raising

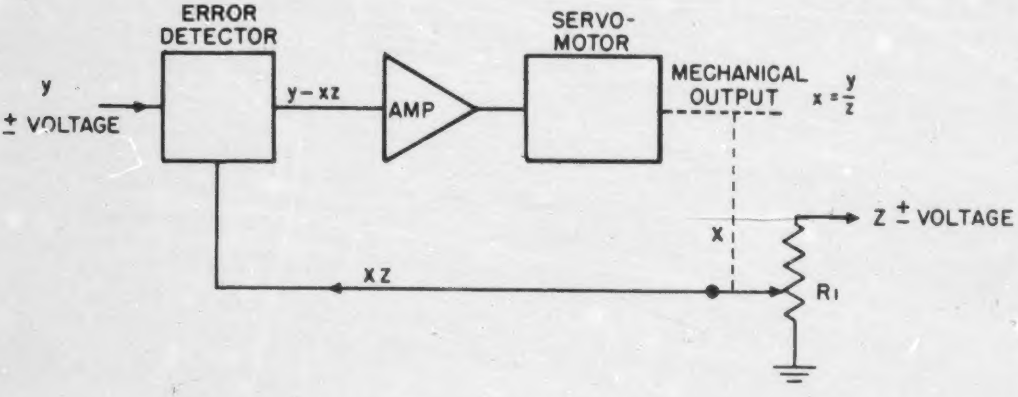


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Figure 7-17.—Division with a servomechanism.

a term to a power or extracting a root of a term, is discussed. It also includes the generation of trigonometric functions.

Most of these operations can be performed by mechanical, electromechanical, and electronic devices. However, one type of device may be more adaptable to a particular operation than another when considering the requirements of an aviation electronics computer. Nonlinear mathematical operations may also be performed by special applications of linear devices previously discussed. For example, a term may be raised to the second power by simply multiplying it by itself, using some type of linear multiplier.

POWERS AND ROOTS

A variety of methods are used in avionics equipment for solving problems involving powers and roots. The most common method utilizes electromechanical principles.

The solution of a navigation problem requires use of devices capable of raising terms to a power. In most cases, the term is raised to the second power (squared).

There are several electronic circuits capable of performing this operation. Perhaps the simplest of the group is a modified use of the multiplying circuit previously discussed and shown in figure 7-13. By applying the input value to both grids 1 and 3, the output voltage will be proportional to the square of the input.

Another electronic circuit capable of squaring is called the squaring amplifier. It consists of a paraphase amplifier with its outputs driving push-pull triode amplifiers. Its output is also proportional to the square of the input, requiring a change in scale factor.

A common electromechanical method of raising a term to a power is by successive multiplication with potentiometer multipliers. (See fig. 7-14.)

When the equation is $y = kx^2$ ganged po-

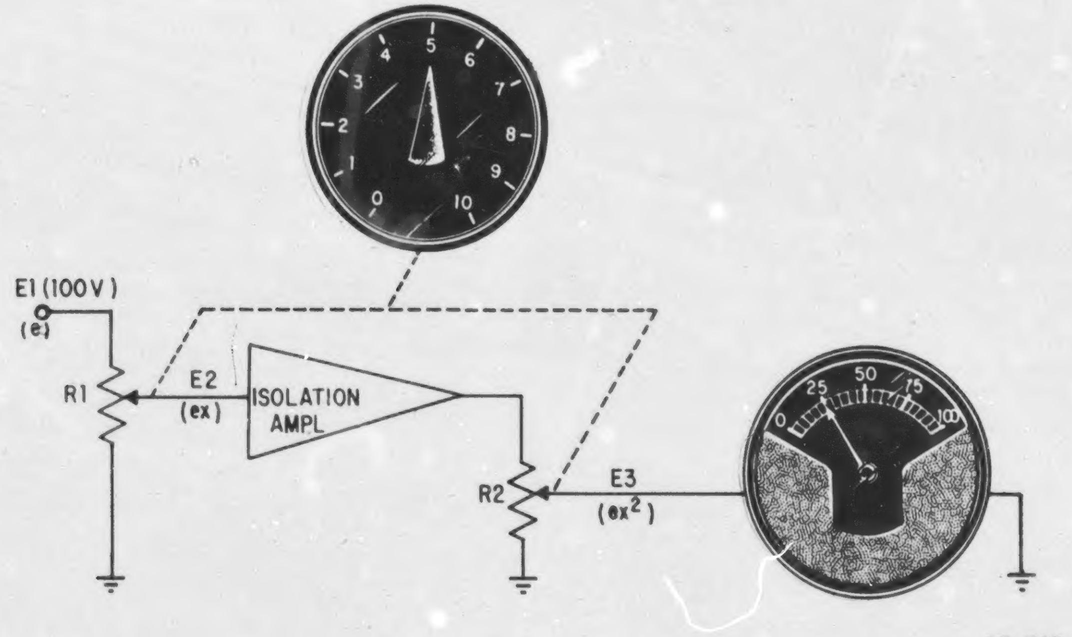


Figure 7-18.—Powers by successive multiplication.

tentiometers may be used, provided that x is the common shaft position of the potentiometers. This circuit is illustrated in figure 7-18. The variable x may be raised successively to higher powers by repeating this circuit with additional potentiometers.

The voltage (ex) at the variable tap of R1 is at all times proportional to x. The voltage at the tap of R1 is fed through an isolating circuit to R2. The voltage to R2 is equal to ex. This voltage is again multiplied by x and the output voltage at the variable tap of R2 is equal to x times ex, or ex^2.

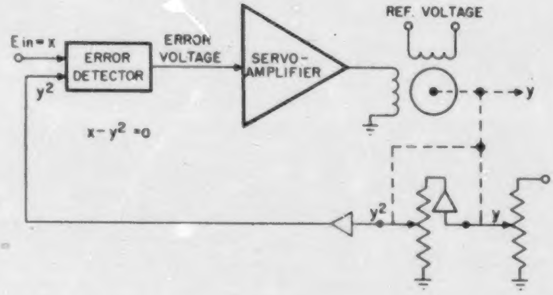
Using the values shown in figure 7-18, the squaring process may be explained mathematically as follows:

The fixed voltage e corresponds to the constant k, in the expression $y = kx^2$. Placing the two forms of the equation side by side for comparison,

$$\begin{aligned} y &= kx^2 & \qquad e_o &= ex^2 = [ex]\,(x) \\ y &= 100(0.50)^2 & \qquad e_o &= [(100)(0.50)]\,(0.50) \\ y &= 25 & \qquad e_o &= 25 \end{aligned}$$

The mechanization of these equations in terms of percentage of travel by the potentiometer wipers, can be described as follows: If the control of the potentiometers (x) is calibrated in equal units from 0 to 10, then 5 on the dial would represent 50 percent of total travel and 50 percent of E1 would appear at the wiper of R1. With this 50 volts applied to R2 and the wiper of R2 at 50 percent of its travel, 25 percent (50 percent × 50 percent) of E1 will appear at the wiper of R2. If the output meter is calibrated to read 0=100 volts, then in this case it will read 25. In effect, we have squared the number 5. The power to which a quantity can be raised is limited by the practical limits of voltage available to R1.

The root of a term may be extracted by either electromechanical or electronic devices. In fact, any multiplying or integrating device capable of raising a term to a power and also capable of producing inverse functions can be used to produce roots. However, the extracting of roots is usually accomplished by electromechanical devices.



AQ. 513

Figure 7-19.—Square root servomechanism.

An electromechanical device for extracting the root of a term or number is the servomechanism feedback loop which utilizes ganged potentiometers as shown in figure 7-19. The equation $y = \sqrt[n]{x}$ may be written as $x = y^n = 0$ by raising both sides to the nth power and transposing the y term. Now the equation is in required form for servomechanism instrumentation.

Square root is solved by multiplying the output quantity by itself and using this value as the feedback term. The output of the square root device is in the form of a shaft position, y.

TRIGONOMETRIC FUNCTIONS

Trigonometric processes can be carried out with inductive resolvers, potentiometers, or all-mechanical devices. Electronic networks consisting of R and C are also sometimes used to perform some trigonometric functions, such as vector addition.

The trigonometric functions most often used in avionics equipment are sines and cosines of angles. However, the four remaining functions may be computed based on the sine and cosine. Those who are not familiar with trigonometry should study Mathematics, Vol. 2, NavPers 10071-B.

Electromechanical Devices

The inductive resolver is one of the most common a-c electromechanical devices used to

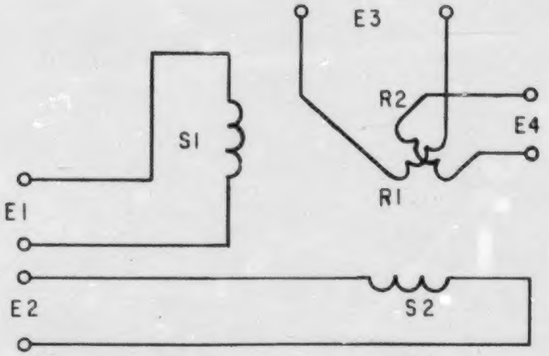


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Figure 7-20.—Inductive resolver diagram.

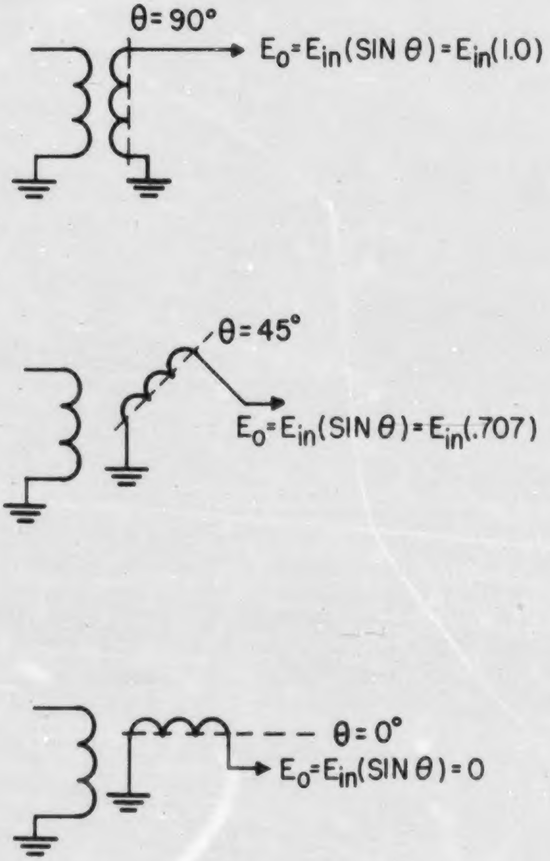

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Figure 7-21.—Inductive resolver action.

generate trigonometric functions. It is basically a right triangle solver, using windings to represent the sides and magnetic flux to represent the hypotenuse. The shaft rotation corresponds to one of the angles of the right triangle that is to be solved.

The construction is very similar to that of a synchro, except that both the rotor and stator have two windings oriented 90° from each other as shown in figure 7-20. Their primary use is to resolve a voltage into two components at right angles or to combine two component voltages into their vector sum.

When a rotor winding is parallel to one stator winding, the device acts as a one-to-one transformer. As the rotor winding is rotated, the voltage induced depends on the sine of the angle of rotation times the applied voltage.

$$E_o = (E_{in})(\sin\theta)$$

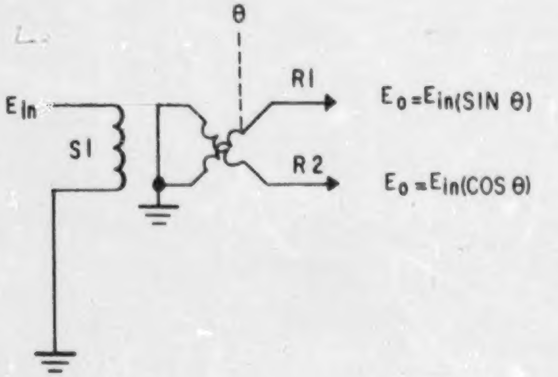
Figure 7-21 illustrates the action of the inductive resolver for three positions.

If the second rotor winding, as shown in figure 7-22, is at right angles to the first winding, its output will correspond to the cosine of the rotation angle, since

$$\cos\theta = \sin(\theta + 90^\circ)$$

Resolvers are low-impedance devices. Isolation amplifiers are generally used as driving circuits if the inductive resolver input signal originates in a high-impedance source, such as a potentiometer. Isolation amplifiers have a low output impedance and can correct for any undesirable phase shift developed in the resolver. Since inductive resolvers operate only with a-c voltages, they cannot be used in d-c analog computers.

Some operations require that the computer be capable of transforming data from a polar to a rectangular coordinate system. If the position of a point or object is defined by a vector, the polar dimensions of the vector may be converted to rectangular coordinates. The vector quantity.

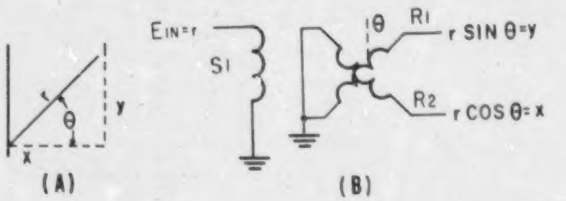


AQ. 516

Figure 7-22.–Inductive resolver with 2-phase winding.

distance r and angle θ, may be resolved into horizontal and vertical distances, x and y respectively, with a 2-phase inductive resolver. By feeding a voltage representing the distance r into the stator winding and rotating the rotor shaft through an angle corresponding to θ, voltages representing x and y are produced at the rotor windings as shown in figure 7-23.

Sine and cosine potentiometers are special devices for the selection of a voltage that is indicative of either the sine or cosine of an angle. Output voltages proportional to the product of the input voltage and either the sine or cosine of the angle through which the shaft is rotated can be obtained from the specially designed potentiometers.



AQ. 517

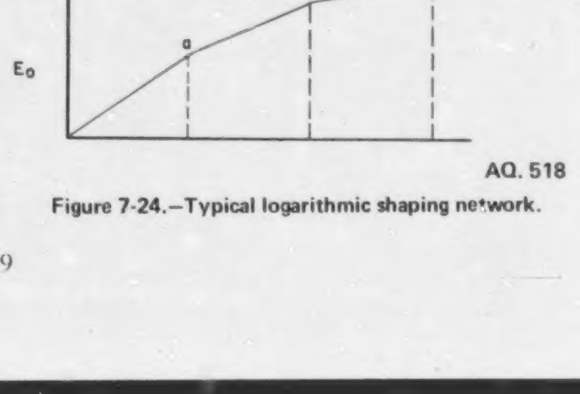
Figure 7-23.–Polar to rectangular transformation.

LOGARITHMS

The application of logarithms to perform multiplication and division was briefly discussed earlier in this chapter. A study of logarithmic processes in Mathematics, Vol. 2, NavPers 10071-B, will indicate that logarithms are also useful in raising a term to a power or extracting a root of a term with the use of logarithms. In this section we are primarily concerned with computing devices for obtaining the logarithm of a term.

Diodes and contact rectifiers under some conditions have nearly exponential variation of current with voltage, or logarithmic variation of voltage with current. However, the operating limits of a single diode are surpassed by the requirements of most airborne computers. This limitation necessitates the use of circuits such as the one shown in figure 7-24 to produce logarithmic functions.

The purpose of this circuit is to produce an output voltage that is proportional to the logarithm of the input current. Referring to figure 7-24, it should be noted that R2, R4, and R6 form a voltage divider network. The cathode of each rectifier is connected through a resistor to some point on the voltage divider. This effectively acts as bias, causing each rectifier to



AQ. 518

Figure 7-24.–Typical logarithmic shaping network.

be cut off until its plate reaches a potential higher than its cathode.

As the input current is applied, current flow will be up through R1 producing an output voltage proportional to the current ($E = IR$). As the current, hence the voltage drop across R1, becomes great enough, the positive voltage at the top of R1 will become great enough to bring CR1 into conduction. As soon as CR1 conducts, it effectively places R3 in parallel with R1, lowering the total resistance and producing less voltage drop for a given increase in input current. This accounts for the bend in the curve at point a. The circuit response curve illustrates how the slope is successively reduced as additional rectifiers come into conduction. It should also be noted that an increased number of rectifiers could result in a more perfect curve.

There are several means available of obtaining the antilogarithm of a quantity. This may be done either by employing an exponential characteristic directly or by the use of a feedback loop. Implicit methods may also be used, such as taking the derivative of the term in order to eliminate the logarithm in the equation.

CALCULUS

Calculus is a branch of mathematics that deals with the rate of change of a function and with the inverse process which is the determination of a function from its rate of change. The process of determining the rate of change of one variable with respect to another is called differentiation or differential calculus. The process of determining the sum of many minute quantities is referred to as integration or integral calculus.

DIFFERENTIATION

Before going into the actual process of differentiation, the terminology used is discussed briefly. Consider the equation $x = f(y)$. It should be read as: x equals a function of y. If the derivative of x is taken with respect to y, then it would be written as:

$$\frac{dx}{dy} = d\,\frac{[f(y)]}{dy}$$

which, in notation form, is

$$\frac{dx}{dy} = f'(y)$$

$$dx = f'(y)dy$$

Note that the prime indicates the first derivative of the function. When the derivative is a time derivative, it is common practice to shorten the symbol even more, especially for diagrams. For example, dx/dt (where t represents time) is often shortened to $\dot{x}$ (note the dot over the x).

Although y represents any variable, we are generally interested in the derivative with respect to time. The derivative of a quantity with respect to time can be thought of as the time rate of change of that quantity. For motion along a straight line, for example, the derivative of the distance traversed with respect to time is the velocity or the time rate of change of distance. Similarly, the derivative of a voltage with respect to time is the time rate of change of that voltage. Figure 7-25 shows a graphical representation of the derivative of a voltage. If a voltage E_{in} is changing at a constant rate as shown in (A) of figure 7-25, then the derivative E_o of that voltage has a constant value as shown in (B).

Electronic Methods

The rate at which an input voltage is changing can be obtained from a simple series-connected resistor and capacitor circuit as shown in (A) of figure 7-26. Notice that the output voltage of

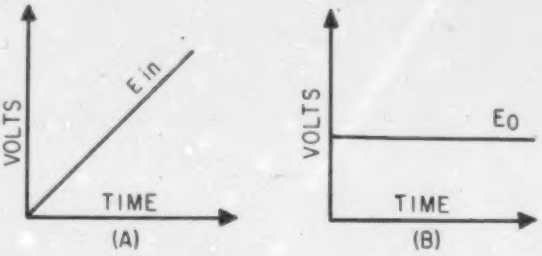


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Figure 7-25.—Graphic representation of the derivative of a voltage.

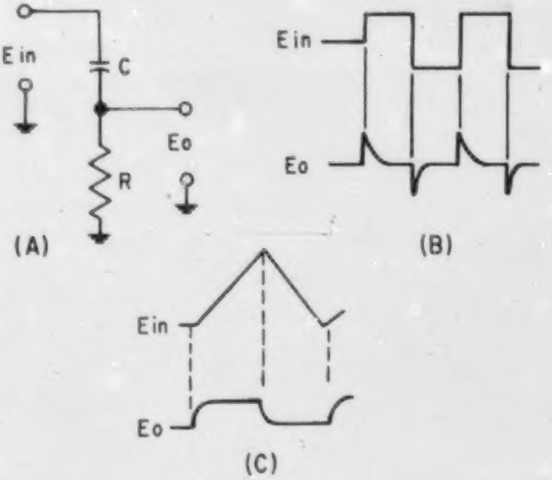

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Figure 7-26.—Simple differentiating circuit.

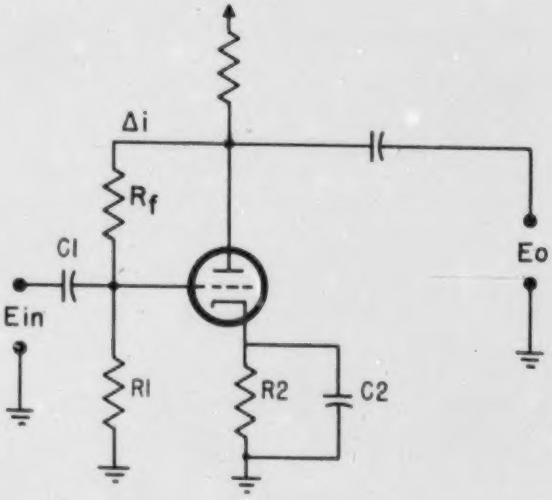

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Figure 7-27.—Differentiating circuit employing a feedback amplifier.

this circuit appears across the resistor. With the proper values of R and C to provide a short RC time constant and with a square-wave input voltage E_{in}, the output voltage E_o will be that shown in (B) of figure 7-26. When the rate of change of E_{in} is greatest, the value of E_o is greatest; when the rate of change of E_{in} is zero, the output E_o tends toward zero. The derivative of a triangular wave or a sawtooth wave is shown in (C) of figure 7-26. These facts illustrate that the output voltage is approximately equal to the time rate of change (derivative) of the input voltage. For a review of RC differentiating circuits, see Basic Electronics, Vol. 2, NavPers 10087-C.

The primary disadvantage of the simple differentiating circuit is the time required for the output voltage to become equal to the derivative of the input voltage. Shortening the RC time constant to decrease this time decreases the amplitude of the output voltage.

A feedback amplifier differentiator is shown in figure 7-27. This type of differentiator is superior to the simple differentiator circuit, because its output voltage approximates the derivative of the input voltage in a much shorter time and with greater accuracy. However, the differentiator circuit using a feedback amplifier is limited to use in those situations where introduction of electronic noise is not a serious problem. They act as high-pass filters, and this causes amplification of circuit noise and introduces instability in the amplifier. In a circuit where noise is already a problem, differentiation must be accomplished by setting up an implicit function; this allows indirect differentiation by operating "in reverse" and using integrators.

In the following discussion involving the application of a feedback amplifier, it is presupposed that the reader has a thorough understanding of the theory of negative feedback amplifiers. Therefore, anyone not possessing this understanding should study Basic Electronics, Vol. 1, NavPers 10087-C.

Before discussing the operation of the differentiator amplifier circuit, the following conditions are established:

1. The amplifier must be biased so as to operate near the center of its linear range and not draw any grid current when operating within its specified limits.

2. The grid voltage is near ground potential and changes only a very small amount when the input signal varies. This occurs because the feedback voltage tends to prevent any change in grid voltage.

3. Since the grid voltage remains almost constant, any change in plate voltage due to an input signal appears almost entirely across the feedback resistor, causing a corresponding change in current through it. Therefore, the output voltage E_o is given by the formula

$$E_o = -\Delta i R_f$$

In this formula, E_o is the change in plate voltage (a-c component) resulting from an input signal applied to the grid, Δi is the change in current flowing through the feedback resistor, and R_f is the feedback resistor.

The formula can be restated in more simple terms, keeping in mind that a differentiator produces an output only when there is a change in the input voltage. The amplitude of the output voltage (a.c.) is equal to the change in feedback current (a-c component) multiplied by the resistance of the feedback resistor. The negative sign serves to emphasize the fact that a polarity inversion is introduced by the amplifier.

Consider the action of the circuit with a constantly changing voltage applied. (See fig. 7-27.) For simplicity of explanation, consider a back-to-back sawtooth that is starting downward from its apex. As the negative-going signal starts downward, electrons from the grid side of C1 starts to flow through R_f (electrons are attracted to the higher potential of the plate) causing the grid voltage to drop. This action reduces plate current, causing a rise in plate voltage. A portion of the plate voltage increase is fed back to the grid, causing it to rise in potential. However, since the feedback voltage is only a small portion of the plate signal, the grid cannot come back to its initial voltage. The grid and plate will reach a state of equilibrium almost instantly and remain balanced as long as the current through R_f is constant. With an input voltage which is linear, the discharge current of C1 will remain constant through R_f until the input reverses its direction.

Since the plate is the source of the output, observe its action closely. Remember that the output is only the a-c component of the plate voltage. When the input signal started downward, the plate voltage shot up and leveled off instantaneously and remained at this level until the input signal reversed its direction. This produced a square-wave output that is opposite in polarity to the input. The other half cycle will produce a similar output. Therefore, the output is a voltage waveform indicative of the rate of change of the input voltage.

Electromechanical Methods

When the derivative of a voltage is desired, a generator driven by a servomechanism may be used. In this case the servo transforms the voltage to be differentiated into a corresponding shaft position. A generator which is driven by the servo shaft produces an output voltage proportional to the speed of the motor. The generator voltage is a derivative of the rotor displacement with respect to time or a measure of the rate of rotor rotation. (See fig. 7-28.)

The derivative range is limited by the response of the servomechanism. A system having moving parts with appreciable inertia cannot respond satisfactorily to a voltage step function, where the slope is infinite.

INTEGRATION

Integration is the process of summing up an infinite number of minute quantities. However, in the solution of most navigation problems, integration is usually the summing of certain quantities in respect to time. For example, taking the integral of velocity between certain limits of time will give the distance traveled.

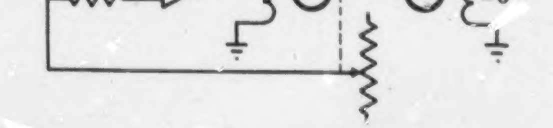

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Figure 7-28.—Electromechanical differentiator.

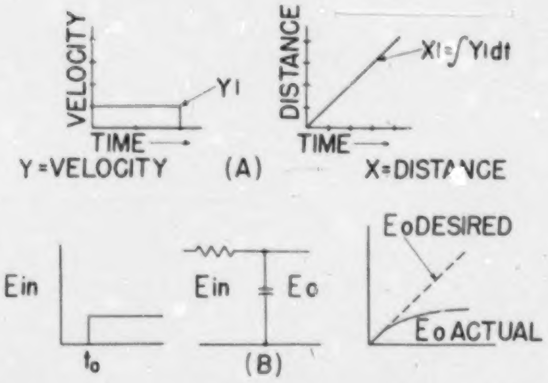

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Figure 7-29.—Integration of area.

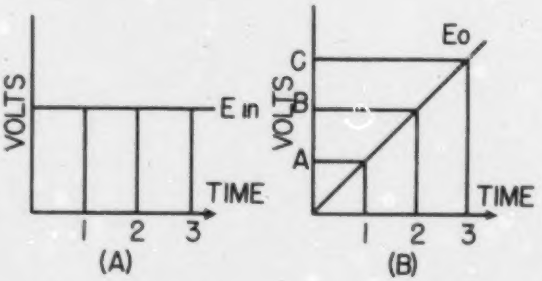

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Figure 7-30.—Graphical representation of integration of a voltage.

The process of integration is analogous to determining the area under a curve. In the case of a step function input, the "curve" may be considered as a rectangle having one side variable with time. In figure 7-29(A), the solid curve Y1 shows the velocity at any time, in this case a constant velocity. The distance traveled is equal to the velocity multiplied by the time, and with proper scale values, the distance is given by the numerical area under this (rectangular) curve; that is, area = height (or velocity) multiplied by length (or time). On the distance-time diagram, the sloping line X1 shows the total distance traveled at any instant of time; and the larger the step input the steeper the slope of the line in the distance-time diagram.

The distance traveled, x, must continue to increase as long as there is a positive value of velocity, y. When x is represented by a voltage, there are limitations on its maximum value due to circuitry to be used.

The integral of a d-c voltage is a voltage with a constant slope as shown in figure 7-30. There is normally no need of integrating d-c voltages but this effect is identical to the voltage wave for step inputs.

A simple integrator is shown in (A) of figure 7-31. Here a square-wave voltage is applied to the input, and the output voltage appears across the capacitor. During the positive portions of the input voltage, the output voltage is the sum of all the positive quantities, which results in an increasing voltage. During the negative portions of the input voltage, the output voltage is the sum of all of the negative quantities in the input, which results in a decreasing voltage. Study the waveforms in (B) of figure 7-31 and compare them with the output of the simple differentiator circuit. The integrator output and the differentiator output combined equal the instantaneous input voltage, except for circuit losses.

For further details concerning simple integrator circuits, review the discussion of this topic in Basic Electronics, Vol. 2, NavPers 10087-C.

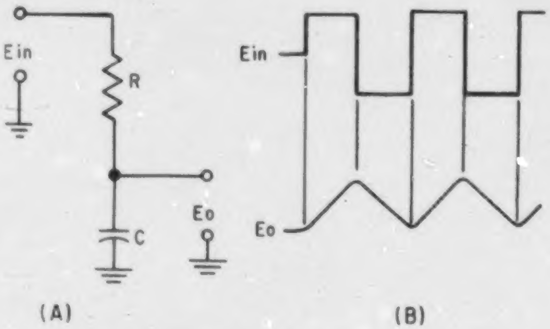

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Figure 7-31.—Simple integrating circuit.

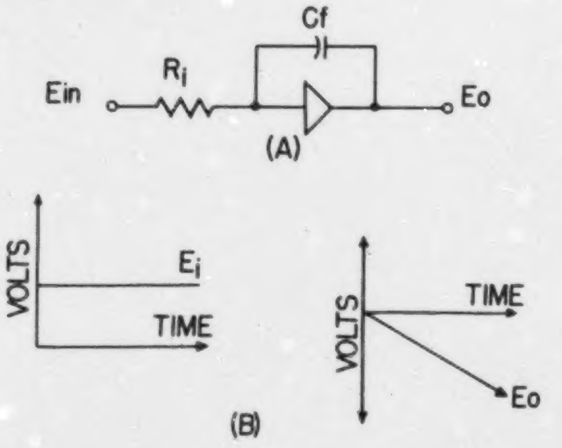

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Figure 7-32.—A common integrating circuit.

An integrating amplifier circuit utilizing a feedback amplifier is shown in figure 7-32. This circuit is very similar to the differentiating amplifier circuit discussed previously. However, it should be noted that the negative feedback is coupled from plate to grid with a large coupling capacitor. This capacitor, along with the input resistor and load resistor, performs the integration. The amplifier functions only to improve its response and linearity. The input circuit also utilizes an isolation resistor (R1) to allow the grid to be maintained at an almost constant potential when an input signal is applied.

The output is based on the rate of charge, or discharge, of the feedback capacitor. The amplifier functions to maintain the charge, or discharge, of the integrating capacitor in the linear portion of the RC curve. The net effect is that the capacitor voltage does not oppose the input voltage and the capacitor charging current is a direct function of the input signal voltage.

GROUPED OPERATIONS

Thus far in this chapter computing devices for performing various mathematical operations have been discussed individually. At this point several of the instruments or devices are grouped together for the solution of a problem. It is not intended that such grouping will comprise a workable computer, but rather to show that grouping devices allows the solution of more complex equations which may involve only a small portion of a complete computer.

PROBLEMS ENCOUNTERED

When various devices are selected to carry out a grouped operation, certain problems are almost certain to develop. Such problems are present even in the grouping of the simplest devices. Here again this information is presented not to help you design a computer, but to aid you in understanding the more complex computers.

Change of Representation

With the connecting of two or more computing devices, the use of two or more methods of representation are frequently required. The output of the first device may not have the same representation as required by the input of the second device. An example might be the multiplication of two voltages by a potentiometer type multiplier. To successfully multiply, one of the voltages would have to be represented by a shaft rotation.

Scale Factor

Another problem that must be considered when grouping two or more devices is that of scale factor. As pointed out previously, a change of scale factor takes place any time the device produces a proportional output. Such devices include those which perform the operations of adding, multiplying, dividing, etc.

Impedance Matching

When the output of one electronic circuit is fed to another, the input impedance of the second circuit or stage may affect the operation of the first. Therefore, it is important that the input impedance of the second circuit be matched to the output impedance of the driving stage. A mismatch may result in an error in the computer, making the complete computer inaccurate. Two devices often used between two computing circuits are the cathode follower and impedance matching transformers. Impedance matching in the use of electrical components, such as resolvers and control transformers, must also be considered.

Speed of Computation

The speed of response of a device is important in grouped operation. Some devices have a shorter response time than others. For example, a device with a minimum speed of computation time, when required to function longer than the minimum time, may lose a considerable percentage of its accuracy. The overall accuracy of a group of devices could be reduced below the desired tolerance due to one device requiring a longer time to function than the rest of the group. The speed of response is an important factor in regard to the stability of computers utilizing feedback.

TYPICAL EQUATION SOLUTION

In the solution of a typical tactics problem, it is often necessary to find the hypotenuse of a right triangle when the length of the two sides is given. Airborne analog computers normally utilize ground range or horizontal range because ground range rates are more constant than slant range rates. However, to minimize the possibility of error, computed ground range is converted into slant range for comparison with observed radar range. This requires a constant solution from the following equation:

$$r = \sqrt{H^2 + R^2}$$

where

r = slant range
H = altitude
R = ground range

A block diagram of a squaring type triangle solver is shown in figure 7-33. The quantities H and R are squared and summed. The summed quantity ($R^2 + H^2$) is fed to a device that extracts the square root, giving an output equal to r.

A simplified circuit capable of performing the above operation is illustrated in figure 7-34. The quantities H, R, and r are represented by their respective shaft positions. Ganged potentiometers are used for squaring each quantity. A voltage proportional to $H^2 + R^2$ appears across R4, and is fed to a feedback amplifier. Here the signal is amplified and the scale factor is corrected prior to being fed to the difference amplifier.

Potentiometers R15 and R16 are squaring potentiometers with the output being a voltage proportional to r^2. This signal is also amplified and fed to the difference amplifier. If the voltage r^2 is equal to the voltage $H^2 + R^2$, the output from the difference amplifier is zero and the position of the r shaft is indicative of

$$\sqrt{H^2 + R^2}$$

However, if there is a difference in the two inputs, the output signal fed to the servoamplifier will cause the servomotor to rotate in a direction to reduce the difference voltage, thus correcting the output r.

It should be remembered that this example is only one of many possible ways of solving a

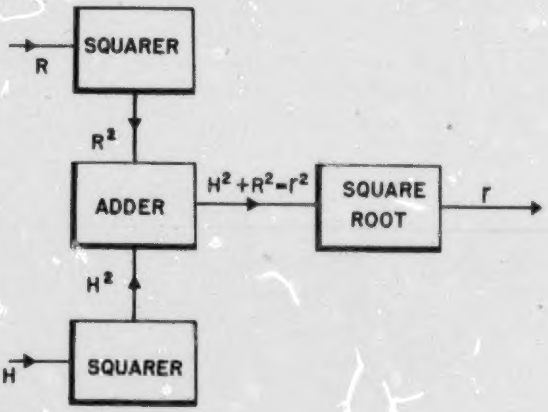

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Figure 7-33.—Block diagram of right triangle solver.

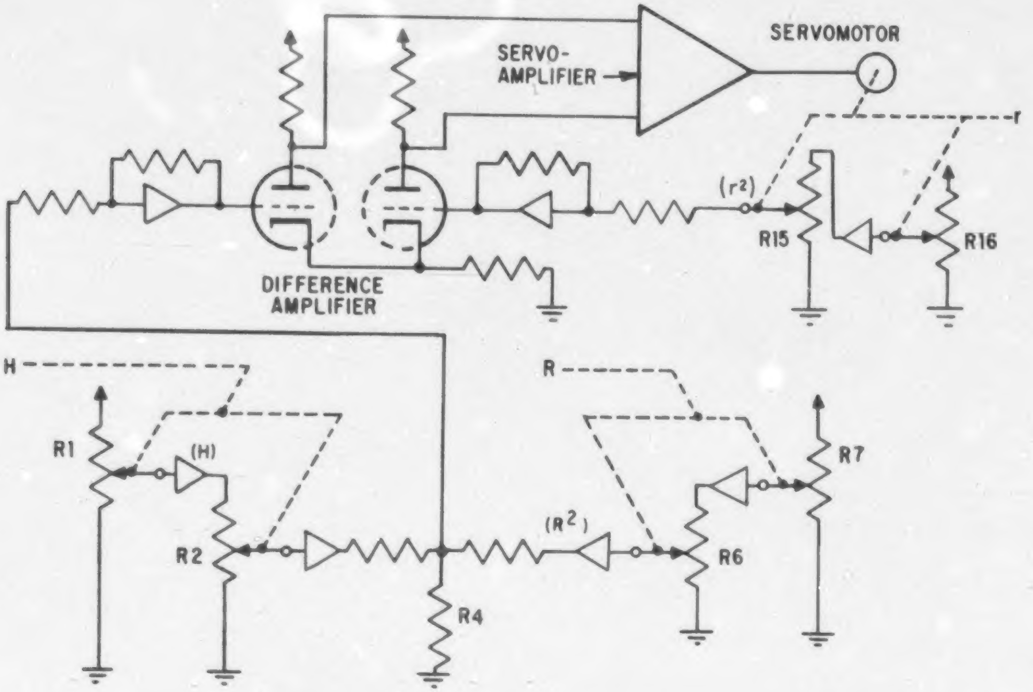

SERVO-
AMPLIFIER
SERVOMOTOR
(r2)
R15
R16
DIFFERENCE
AMPLIFIER
H
R
R1
(H)
R2
R4
(R2)
R6
R7
AQ. 528

Figure 7-34.—Schematic diagram of a right triangle solver.

right triangle. It is included only to show that the devices discussed earlier in this chapter may be grouped for the solution of more complex equations.

There are many applications of the analog type computer in naval aviation. The trend of today's weapons systems is toward computers called hybrids. As previously mentioned, these computers are a combination of both analog and digital computing devices. This arrangement will probably remain for some time since many of the input and output devices must be analog. Input devices of the analog type are required to receive the data from a radar set, airspeed probe, or a shaft position since this type of data is analog in nature.

CHAPTER 8

ELECTRICAL POWER AND GROUND COOLING SYSTEMS

In order to operate and maintain the complex electronic installations of modern naval aircraft, the technician must be familiar with the electric power system of the particular aircraft with which he is associated. Since the electronic installations of aircraft vary widely according to the size and application of the aircraft, the electric power requirements and the electric system components of aircraft also vary. Therefore, the technician must also have a basic understanding of the component parts of the electric system–the power generation equipment, the conversion units, the power control, regulation, and protection components, and the general distribution systems–of typical aircraft.

Today's technician must also have an understanding of the capabilities and limitations of the auxiliary power sources provided for use in ground servicing and maintenance of aircraft. He must be able to operate these units, and must be familiar with the proper procedures for connecting and disconnecting the auxiliary power units to the aircraft. He must know the proper procedures for servicing the auxiliary units, and must observe and enforce all safety precautions and regulations concerning these operations.

The technician must also know the requirements for cooling the various electronic equipment while on the ground. He must be familiar with the sources of auxiliary air and cooling. He must know the operating procedures, as well as the capabilities and limitations of the various cooling units.

This chapter is devoted to a discussion of these topics. In most sections, the topics are discussed in general; in a few instances details are presented as they pertain to specific topics or items of equipment. Coverage of equipments is limited to those expected to be in common usage during the life of this manual.

TYPICAL AIRCRAFT SYSTEMS

The electric power system of an aircraft consists of the power source and its associated controls, the generation system and its associated control and regulation, the conversion units, the feeder and distribution system and its component parts, and the various protective devices used throughout the installation.

Most older types of aircraft used engine-driven generators to produce d-c power at a nominal 27.7 volts. Inverters and dynamotors were used as conversion units to produce the voltages required for operation of the individual equipment. With the comparatively simple installations then in use, this arrangement was satisfactory; however, as the installations became more complex, weight problems arose. The increased weight (which resulted from the addition of more and more inverters and dynamotors) soon became prohibitive. A new approach to the problem was required.

As part of the overall effort to standardize aircraft and electronic installations, the supply and distribution of power offered a logical starting point. The first step was to standardize the supply voltages and power frequencies, and to use generators which would provide the required power. Later in the standardization program, the generation of d-c power was discontinued, and the primary power became exclusively a.c.; the d-c requirement was supplied through transformer-rectifiers. This reduced the number of voltages generated and the number of rotary devices, and allowed the use of smaller conductors in the distribution system. The result was a drastic decrease in the total weight of a given installation, which in turn permitted a more complex installation for a given weight allowance.

Even a partial listing of the considerations involved in any discussion of aircraft electric systems must include the following items in order to be of any real value:

1. A "main generating source" refers to all generator units driven by a specified engine; thus a single-engine aircraft can have only one main source.
2. Multiengine aircraft may have a main generating subsystem for each engine. This is the usual practice, but it is not universally followed.
3. In multigenerator systems, provisions may or may not be made for parallel operation of generators producing similar power. If parallel operation is provided, provisions must also be made for individual operation of the subsystems in the event of a failure within the paralleling system.
4. Adequate frequency regulation and stability in a-c generation systems required some method of speed control of the generator's rotor drive mechanism.
5. Provisions must be made to insure that adequate power is available in each mode of operation. In the event of failure of the aircraft engine or its associated generation system, the maximum amount of power which can be produced is decreased. In the case of single-engine aircraft this automatically constitutes an emergency situation.
6. The failure of a single generator or engine in a multiple installation does not constitute the same degree of emergency as the same failure in a single-engine installation. Although some restrictions are placed on operational capabilities, some degree of safety may usually be maintained with the remaining engines and generators.
7. Provisions should be made to enable use of external power sources for starting the engines while on the ground and for ground operation without using the aircraft engines. The aircraft electric system must include provisions to prevent applying both internally-generated power and externally-furnished power to the system at the same time.

AIRCRAFT ELECTRIC SYSTEMS

The electric system of each model aircraft has features which are peculiar to it alone, while other features are common to most models. This section is devoted primarily to a general discussion of the electrical system of a typical aircraft, with some subsequent details concerning the electric systems of actual aircraft.

Source of Power

The basic source of power for the electrical system is the aircraft engine. An a-c generator requires a constant rotational speed in order to produce a constant frequency output. In most modern aircraft, a constant speed drive (CSD) unit is inserted between the aircraft engine and the a-c generator for this purpose.

The constant speed drive unit acts as a variable-ratio differential transmission system which converts the variable speed of the engine to the constant speed required by the generator. The engine is mechanically coupled to the input of the CSD unit; the output of the CSD is mechanically coupled to the rotor of the generator. Internal coupling between the input and output sections of the CSD unit is usually hydraulic, using the engine's oil supply as the transmission coupling medium. Output speed of rotation is controlled by means of mechanical governors and/or electronic speed regulators.

Generation System

The heart of the electric generation system is the constant-speed, wye-connected, a-c generator. This unit normally produces a 3-phase output voltage of about 120/208 volts at 400 Hz which is subsequently regulated to 115/200 volts. The basic theory of a-c generators is discussed in chapter 16 of Basic Electricity, NavPers 10086-B.

An underspeed switch is normally connected to the output shaft of the CSD unit. This is a centrifugally-operated switch and is normally in the open position; it closes only when the output end of the CSD (which is also the generator shaft) reaches a preset speed of rotation. When the switch is open, the electrical system cannot be energized. An overspeed switch is also sometimes used.

D-C GENERATOR.–In most older aircraft all electric power was generated as d.c. In most of the newer aircraft no d.c. is generated; the d-c requirements are met by transforming and rectifying the a.c. In some presently operational aircraft, however, the main power generation system provides both a-c and d-c voltages from a common unit. In other aircraft models, a separate generator is used to provide the d-c power required for operation of the d-c components. This method is not common in airborne applications because of the limited number of prime movers (engines) available.

The basic theory of d-c power generators is presented in chapter 18 of Basic Electricity, NavPers 10086-B.

EMERGENCY GENERATORS.–In the event of failure or shutdown of the aircraft's engines or main generators, the electric system becomes inoperative. The aircraft, however, must have electrical power in order to maintain adequate flight control. Most naval aircraft incorporate an auxiliary or emergency generator which operates independently of the aircraft engine.

The most common type of emergency generator is the ram air turbine (RAT). It is normally enclosed within the fuselage, being projected into the airstream when its operation is necessary. Driving power for the rotor is derived from the movement of a turbine through the air; it can be operated only in flight or with blast air when on the ground.

Due to its relatively small size, the emergency generator cannot supply the electric loads required for normal operation of the aircraft. Therefore only those systems and equipments considered essential for the maintenance of flight are operable when the aircraft is dependent on the emergency generator.

Because the rotor of the ram air turbine generator turns at a variable speed (dependent on the speed of the aircraft in flight), frequency stability is not so refined as that of the main generators. A governor is usually incorporated to limit rotational speed; the frequency is thus prevented from becoming too high. No solution has yet been found for maintaining operation of the generator when the aircraft speed drops below a certain point. Therefore, in the event of a power-off landing, all electric power and stability control is lost before the aircraft rolls to a full stop.

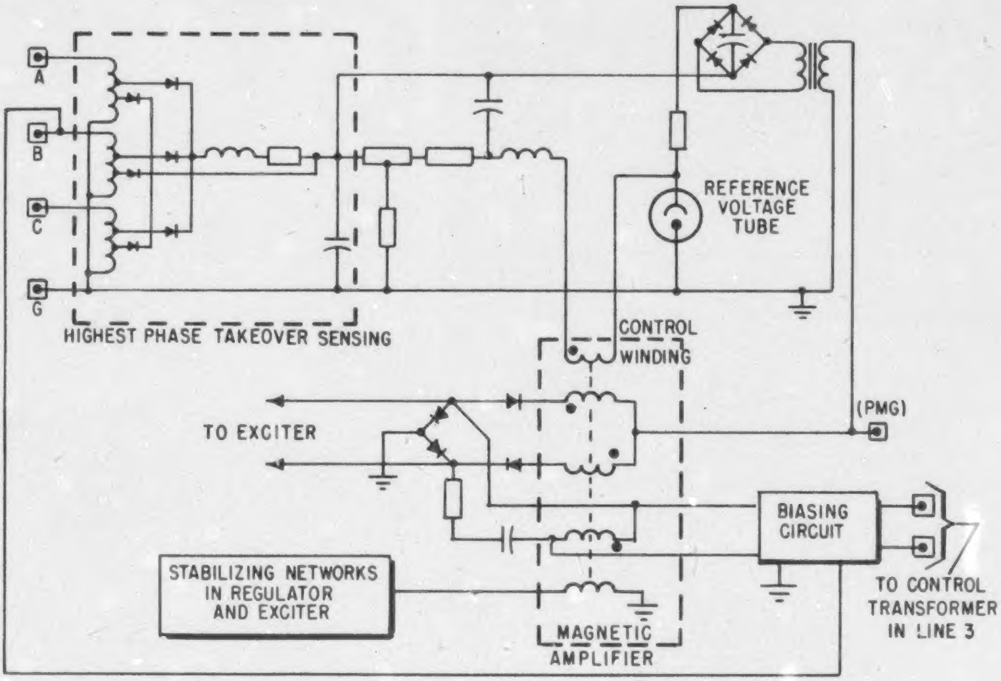
System Voltage Regulation

Voltage regulators are incorporated in all electric generatiosystems. Although similar in basic purpose, the configuration and details of operation vary with each type. Basic theory of voltage regulation and regulator devices is presented in chapters 16 (for a.c.) and 18 (for d.c.) of Basic Electricity, NavPers 10086-B. A practical 3-phase a-c static voltage regulator, specifically designed for aircraft usage, is shown in simplified form in figure 8-1 and discussed in the following paragraphs.

The voltage sensing circuit of the regulator incorporates a highest phase takeover (HPT) circuit developed specifically for aircraft systems. This circuit permits regulation of the average of the 3-phase voltages during normal system operation and during slightly unbalanced conditions of the system. Large unbalanced load conditions result in large unbalanced voltages. The HPT circuit allows regulation of the highest individual phase-to-neutral voltage. The unit thus incorporates the advantages of both the average voltage sensing circuit and the highest phase voltage sensing circuit.

The output of the HPT circuit is compared with an accurate voltage obtained from a cold cathode voltage reference tube. Any difference between the sensed voltage and the voltage reference causes a current to flow in the control winding of a magnetic amplifier. This amplifier is energized by a single-phase a-c voltage, such as that produced by a permanent magnet generator (PMG). The current in the control winding determines the current output of the PMG to the magnetic amplifier output circuit. The output of the magnetic amplifier supplies the control winding of the saturable current potential transformer (SCPT).

If the voltage rises at the generator terminals, the output voltage from the sensing circuit increases. This in turn increases the error signal between the sensing circuit and the glow tube reference, and adds to the current in the control


A
B
C
G
HIGHEST PHASE TAKEOVER SENSING
REFERENCE VOLTAGE TUBE
CONTROL WINDING
(PMG)
TO EXCITER
BIASING CIRCUIT
STABILIZING NETWORKS IN REGULATOR AND EXCITER
MAGNETIC AMPLIFIER
TO CONTROL TRANSFORMER IN LINE 3

AT. 45

Figure 8-1.—Voltage regulator, simplified schematic.

winding of the magnetic amplifier. The increased current tends to increase the magnetic amplifier's output current, which then passes through the control winding of the SCPT and makes it behave more like an air core transformer. This reduces the output power. Since the output power of the SCPT is the input power to the generator field, the terminal voltage of the generator is lowered to its required level.

External Power

Essentially all aircraft have provisions for application of electric power from an external source for starting the aircraft engines and/or for ground servicing and maintenance without operating the engines. This power, while not generated within the aircraft, is part of the overall electric system of the aircraft. It must be in all aspects compatible with the power generated within the aircraft. The internal and external power are not normally utilized at the same time. This is one of the functions of the distribution system, which is discussed briefly below. (The equipments used to supply power in the external mode of the electric system are discussed briefly in a later portion of this chapter.)

Distribution System

Once the electric power has been generated and some of it transformed, it must be distributed to the various components and equipment where it is to be used. In a simple system, with comparatively few equipments and requiring only a single form of electric power, a simple distribution system could be used. In modern naval aircraft, however, with the complex electrical and electronic installations requiring many forms of power, an extremely complex distribution system is required.

Each model aircraft has different electrical requirements; therefore, each distribution system must differ from all others in accordance with individual requirements.

The major area of difference between distribution systems of different model aircraft lies in the switching arrangement used to change electric loads from one source to another in the event of a malfunction.

Long range patrol aircraft normally carry a flight engineer as part of their operating flight crew. The flight engineer is responsible for monitoring the operational status of many different systems within the aircraft. In some aircraft he is responsible for distributing individual electric loads among the various sources so as to provide for essentially balanced loads. He is usually responsible for recycling failed systems when it is assumed that the fault has been corrected. Interceptor and other carrier-based aircraft usually do not have a separate flight engineer. The distribution system for these two systems must be quite different in details, even though they may both incorporate all the basic requirements and capabilities for load distribution.

Power Conversion Devices

In most naval aircraft, the main electric power generation system produces 3-phase a-c power at 400 Hz. All aircraft require various levels and quantities of d-c power, and in many instances a-c power of a different frequency is also required. In these cases, various devices are needed to convert the power from the forms generated into the form required for the specific application. A few important conversion devices are discussed briefly in the following paragraphs.

TRANSFORMER-RECTIFIERS.–The most common conversion device for changing a.c. to d.c. is the transformer-rectifier. The 3-phase, 115-volt a.c. is reduced in a stepdown transformer and then rectified to produce the 28-volt d.c. required for operation of various relays, lights, instruments, mechanical devices, etc. Specific transformer-rectifier units are discussed in the electrical section of the maintenance instruction manual for each model aircraft; the fundamental theory of transformers is discussed in chapter 16, and rectifiers are discussed in chapter 15, of Basic Electricity, NavPers 10086-B.

INVERTERS.–An inverter is a rotating electromechanical device used to convert low voltage d.c. into a.c. It consists essentially of a speed governed d-c motor, an armature and brush assembly, and a permanent magnet inductor type a-c generator, all within a single unit; the armature and the permanent magnet rotor are usually mounted on a common shaft.

The inverter's output frequency and voltage should be checked periodically to assure that they are within prescribed limits. Should adjustment be required, notify the electric shop since adjustment of inverters is a responsibility of the AE rating.

Inverters are normally utilized as an emergency power source and for engine starting when the battery is the only power source available.

System Protection

The aircraft electric system incorporates circuits designed to protect the system from damage which could result from malfunction or nonoperation of components in the generation system. Protection requirements and system components vary in different model aircraft, so the circuits are not standardized in configuration. This discussion is based on functional application rather than on operating theory.

OVERVOLTAGE.–In overvoltage protective circuits, a relay deenergizes the system when the line voltage exceeds preset limits. In a more elaborate system, a "highest phase takeover circuit" and a "reactive biasing circuit" are incorporated to provide added protection. Line voltage is sensed and compared with a reference voltage. If the line voltage is too high, and remains excessive for a preset time interval, the protective circuit assumes control and removes the generator from the line.

UNDERVOLTAGE.–The undervoltage relay removes the generator from the line whenever the system voltage drops below a preset limit; sensed voltage is compared with the same reference as that used in the overvoltage protective circuit. Thus the system is protected whenever the voltage supplied to the line is either above or below the narrow range established by the biasing of the relays.

PMG TRANSFER.–This circuit is used in generation systems in which a permanent magnet generator is used to furnish power for the generator controls. If a malfunction occurs in the PMG (or its leads to the control panel), the source of control power is shifted to one of the phases of the main generator. Shifting of power sources is accomplished without interruption by operation of the permanent magnet generator control transfer relay. Once the system has become deenergized, however, the main generator cannot be built up again using the failed PMG.

ANTICYCLING.–Systems which are protected by disabling relays are inherently subject to cycling operation. That is, when the operation of a relay removes a faulty component from the line, it also removes the cause of its own initial operation; therefore the relay returns to its normal condition and the faulty component is returned to the circuit. If the faulty condition still exists, it trips the relay again, and starts another cycle. Anticycling protection consists of a lockout relay that operates to lock in an open position through a set of its own contacts. Thus the faulty circuit cannot cycle itself–the system remains inoperative until the tripped generator control switch is turned to the OFF position and then returned to the ON position.

P-3C ELECTRIC SYSTEM

This aircraft represents an outstanding example of versatility and flexibility in electric systems. It also illustrates several concepts which will probably find general application in future versions of long range aircraft.

The P-3C Orion is a land-based, four-engine, long range patrol type aircraft used primarily for ASW operations. Its electric system includes three main generators which are driven by engines No. 2, 3, and 4. The No. 1 engine is not used in generating electric power. A fourth generator is mounted on and driven by an auxiliary power unit (APU). Refer to figure 8-2 (A).

Three-phase, 115/200 volt, 400 Hz power is supplied to the a-c distribution buses which are located throughout the aircraft. Refer to figure 8-2 (B) at frequent intervals throughout the remainder of this discussion. Each generator is controlled from the right inboard overhead electrical control panel, and supplies power to the a-c distribution system through contractors located within the main load center.

The No. 2 generator normally supplies the main a-c bus A, and the No. 3 generator normally supplies the main a-c bus B. The No. 4 generator runs as a standby and automatically takes over loads deenergized as the resuit of a failed generator. With a dual failure (including generator No. 4), the APU is started and assumes the loads of the failed generators.

Each generator is provided with undervoltage, overvoltage, underfrequency, overfrequency, feeder fault, lockout, and anticycle protection. In addition, embedded in the alternator stator assembly is a mechanical failure warning device which, in the event of a generator bearing failure, will cause the GEN FAIL light on the center instrument panel to illuminate.

NOTE: The mechanical failure warning circuit is not used in the APU generator system.

Operation of the system during normal flight conditions is entirely automatic. The crew needs only to monitor the control panels at the load centers for any indication of a malfunction.

Control of the system is also automatic during ground operation, except switching to and from external power. Lights are provided on the right inboard overhead panel and at the external power receptacle to indicate when external power is being used. Prior to applying external power to the aircraft, the technician must insure that all switches are properly positioned to receive external power and that all personnel performing maintenance on the aircraft are notified that external power is to be applied to aircraft buses. If electronic equipment is to be operated, air conditioning must be connected to the electronic racks to prevent equipment overheating.

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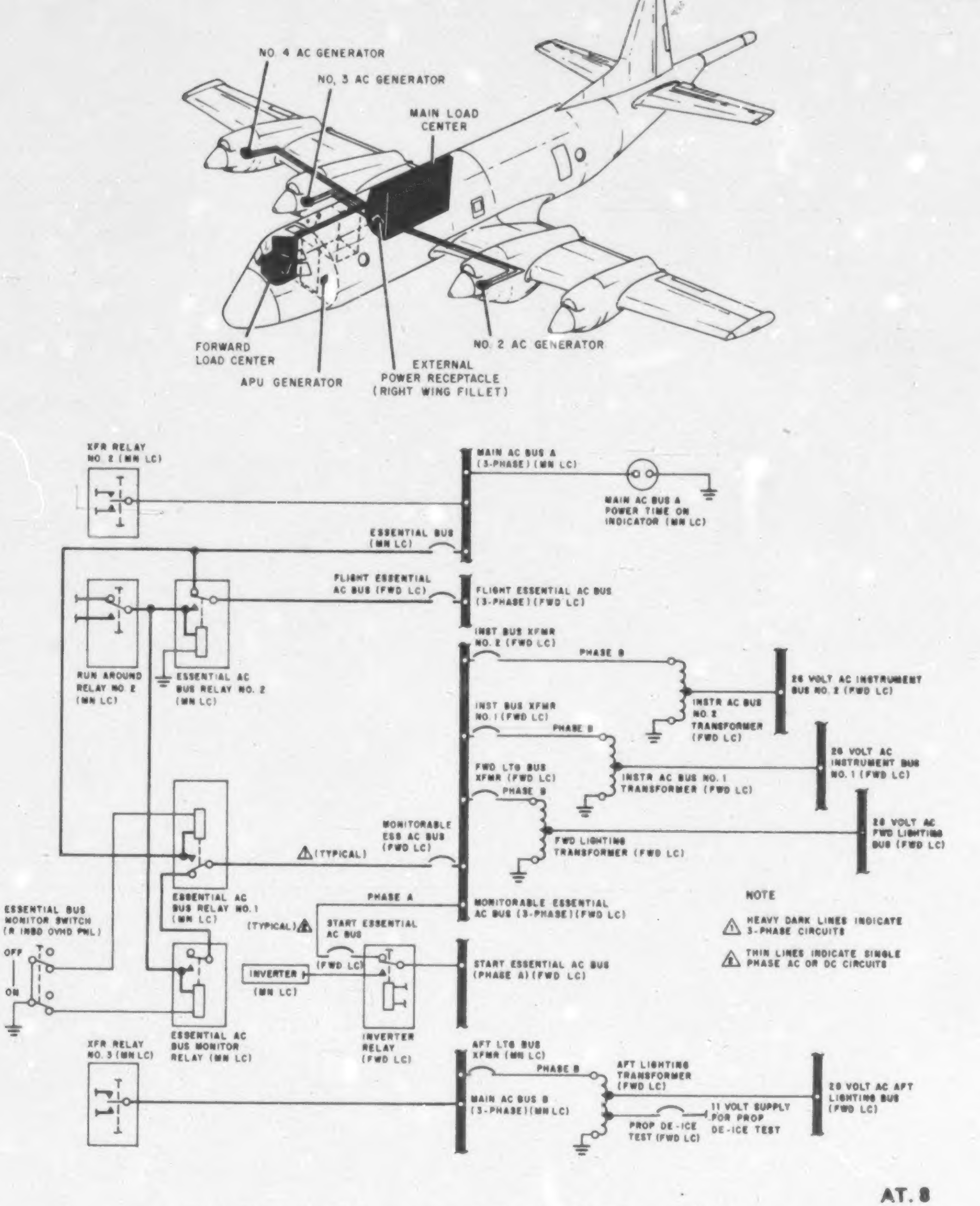

NO. 4 AC GENERATOR
NO. 3 AC GENERATOR
MAIN LOAD CENTER
FORWARD LOAD CENTER
APU GENERATOR
EXTERNAL POWER RECEPTACLE (RIGHT WING FILLET)
NO. 2 AC GENERATOR
XFR RELAY NO. 2 (MN LC)
MAIN AC BUS A (3-PHASE) (MN LC)
MAIN AC BUS A POWER TIME ON INDICATOR (MN LC)
ESSENTIAL BUS (MN LC)
FLIGHT ESSENTIAL AC BUS (FWD LC)
FLIGHT ESSENTIAL AC BUS (3-PHASE) (FWD LC)
RUN AROUND RELAY NO. 2 (MN LC)
ESSENTIAL AC BUS RELAY NO. 2 (MN LC)
INST BUS XFMR NO. 2 (FWD LC)
PHASE B
26 VOLT AC INSTRUMENT BUS NO. 2 (FWD LC)
INSTR AC BUS NO. 2 TRANSFORMER (FWD LC)
INST BUS XFMR NO. 1 (FWD LC)
PHASE B
26 VOLT AC INSTRUMENT BUS NO. 1 (FWD LC)
FWD LTG BUS XFMR (FWD LC)
PHASE B
INSTR AC BUS NO. 1 TRANSFORMER (FWD LC)
28 VOLT AC FWD LIGHTING BUS (FWD LC)
MONITORABLE ESS AC BUS (FWD LC)
⚠(TYPICAL)
FWD LIGHTING TRANSFORMER (FWD LC)
ESSENTIAL AC BUS RELAY NO. 1 (MN LC)
PHASE A
MONITORABLE ESSENTIAL AC BUS (3-PHASE) (FWD LC)
ESSENTIAL BUS MONITOR SWITCH (R INBD OVHD PNL)
(TYPICAL)⚠
START ESSENTIAL AC BUS
OFF
ON
INVERTER
(MN LC)
(FWD LC)
START ESSENTIAL AC BUS (PHASE A) (FWD LC)
NOTE
⚠1 HEAVY DARK LINES INDICATE 3-PHASE CIRCUITS
⚠2 THIN LINES INDICATE SINGLE PHASE AC OR DC CIRCUITS
XFR RELAY NO. 3 (MN LC)
ESSENTIAL AC BUS MONITOR RELAY (MN LC)
INVERTER RELAY (FWD LC)
AFT LTG BUS XFMR (MN LC)
PHASE B
AFT LIGHTING TRANSFORMER (FWD LC)
MAIN AC BUS B (3-PHASE) (MN LC)
28 VOLT AC AFT LIGHTING BUS (FWD LC)
11 VOLT SUPPLY FOR PROP DE-ICE TEST
PROP DE-ICE TEST (FWD LC)
AT. 8

Figure 8-2.—Electric power distribution in a P-3C, simplified.

F-4B ELECTRIC SYSTEM

The F-4B was selected for discussion in this chapter because it offers an example of the continuous process of improving the reliability and simplifying operation of the overall electric system.

The F-4B "Phantom II" is a carrier-based, two-engine, high speed, high altitude, jet interceptor type aircraft. The engines operate at varying speeds according to power settings; therefore a separate CSD unit is needed to provide the generator with a constant speed of rotation. The main power generation system produces a well regulated 115/200-volt, 3-phase, 400-Hz a.c. Part of the a-c power is transformed and rectified to 28-volt d-c power. The system utilizes the static excitation and regulation systems, and incorporates numerous protective features. While some main a-c buses are operated in parallel, this operational feature is being phased-out in an effort to simplify the overall operation of the system.

New versions of the basic aircraft have incorporated an automatic CSD disconnect system. In older models, the engine was shut down whenever overheating of the generator or CSD unit was indicated. This required operation on single engine and attempted air-starts of the secured engine, with many aborted missions and emergency alerts. With the new unit installed it is no longer necessary to secure the engine, unless the cause of overheating is low oil supply in the engine-CSD-generator system (all three units use a common oil supply for cooling).

Another recent modification, the use of brushless generators, has resulted in increased power output ratings coupled with improvements in the control and regulating components. The modification has decreased total weight, improved reliability, and lowered maintenance requirements.

In early versions of the aircraft, damage to the transformer-rectifiers was frequently caused by the application of external power with reversed phase, improper voltage or frequency, or some other defect. A fuse has been installed in the external power circuit to protect the external transformer-rectifier from damage when any parameter of the external power falls outside tolerances.

A problem common to many aircraft involves the ram air turbine (RAT) emergency generator. In early versions of the Phantom II, the emergency generator supplied hydraulic power, in addition to the electric power, for use when both engines were inoperative. This combined requirement limited the RAT to fairly high flying speeds and resulted in the loss of emergency power prior to touchdown in the dead-engine emergency landing. Recent modifications have allowed removal of the hydraulic provisions from the RAT. Improvements to the turbine and its associated generator have permitted the production of adequate emergency electric power at a much lower speed. The newer aircraft can maintain emergency electric power with a speed below that of normal touchdown. Since power decreases rapidly after touchdown, a cutout switch has been installed in the landing gear system. This switch removes the emergency generator from the line upon touchdown and protects the essential bus equipments and components from the effects of low voltage and frequency.

CIRCUIT PROTECTION AND CONTROL DEVICES

The electric system of an aircraft is protected from damage and failure by fuses, current limiters, and circuit breakers. Control and distribution of power is accomplished by the use of switches and relays. Each of these components is available in many styles and sizes, some of which are ideally suited for use in aircraft while others are limited to use in shop installation.

Complete coverage of fuses, current limiters, and circuit breakers is presented in chapter 14 of Basic Electricity, NavPers 10086-B, and chapter 4 of this manual.

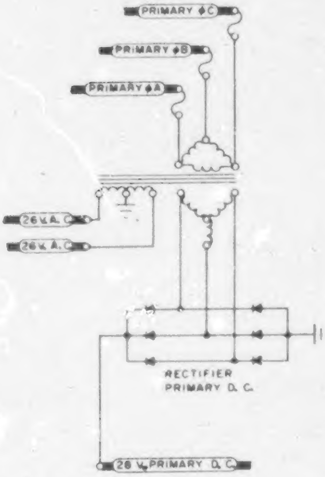
RECTIFIER UNITS

The use of a-c generators for primary electrical power in modern naval aircraft has been mentioned previously. One of the reasons for this is the saving in weight.

The size of wire required to deliver a given wattage can be considerably smaller if the voltage is 115 volts a.c. rather than 27.7 volts d.c. Due to higher voltage and a four-wire (grounded neutral) system, the current carried in each wire is only a fraction of that required for the same power in a 28-volt d-c system. This permits the use of much smaller aircraft wiring with a great saving in weight. The a-c generator itself, especially in the larger sizes, is lighter than a d-c generator of comparable output. Many of the components for system control and protection are also lighter than comparable d-c components.

Even though the d-c generator is eliminated by the utilization of a.c. as a primary source of power, d-c voltages are required for proper functioning of many systems. This d-c voltage is obtained from a transformer-rectifier assembly.

Figure 8-3 is a schematic drawing of a transformer-rectifier unit. The transformer is a 3-phase, 400 Hz, stepdown type. The input is 115 volts a.c. to a delta connection, and the output is 22 volts a.c. across each leg of a wye connection. The rectifiers are of the selenium dry disk type, forming a bridge unit. After rectification (and minus the voltage drop across the rectifier), the output is 28 volts d.c. (Refer to chapter 16 of Basic Electricity, NavPers 10086-B for discussion of 3-phase power components.)



AT. 64

Figure 8-3.–Transformer-rectifier.

AUXILIARY POWER SOURCES

The electric power requirements for starting and servicing modern aircraft are very high. Even in those aircraft which have batteries installed, routine servicing and operational testing of the electronics system require that either the aircraft engines be operating or that an external source of electric power be used.

There are many auxiliary power units (APU's) available for supplying electric power to the aircraft for engine starting, ground servicing, and operational testing. External power receptacles are mounted on all aircraft to provide a means of connecting the external sources to the aircraft.

Some aircraft are also furnished with an airborne auxiliary powerplant (APP) installed aboard or attached externally to the aircraft. The auxiliary powerplant usually consists of an independently operated gasoline engine or turbine which drives a generator. The generator supplies power to the electric system on the ground and in the air. Although the airborne auxiliary powerplant is not capable of supplying the entire load requirements for normal operation of all equipment, it does have the capacity to furnish limited loads for ground servicing or for emergency use in flight.

This section presents a brief discussion of ground- and ship-based auxiliary power units, airborne auxiliary powerplants, and the main power sources normally found in aircraft hangars and on carrier flight decks.

AUXILIARY POWER UNITS

In this discussion the term auxiliary power unit is limited to those units which are portable, but are not installed aboard the aircraft. The units may be self-propelled, towable, or merely transportable; they may use diesel fuel, jet fuel, or gasoline or electric motors. The generators may be driven by the unit's engine or it may have its own prime mover. Several types are discussed; however, before beginning a discussion of specific types of individual models, several generalizations should be mentioned.

When moving the APU into the vicinity of the aircraft, care should be taken to avoid collision with aircraft or other equipment. Flight lines and aircraft parking areas are normally crowded, and space between aircraft and equipment may not be sufficient to allow passage of the APU. Equipment and/or aircraft may have to be moved and repositioned to permit access to the aircraft to be serviced. When movement of the aircraft is necessary, the line crew should be notified, and requirements should be outlined. Local procedures and policies must be followed, and line safety regulations observed. Under NO conditions should the APU be used to move the aircraft, not even "a couple of feet."

Once access to the aircraft has been gained, the APU must be connected to the aircraft. Each unit has its own procedures for operation, but some general considerations apply to all. Prior to connecting the APU to the aircraft to be serviced, all aircraft power switches should be checked and placed in the proper position. (This requires familiarization with the aircraft; the information is available in the Maintenance Instructions Manual for each model aircraft.)

Prior to making the actual connection, the cable and the receptacle should be inspected carefully for general condition and for correct polarity/phase. Many flights are aborted because external power cables have been inserted into aircraft with polarity or phase reversed due to careless insertion or defective cables.

The APU should not be connected to the aircraft with a "hot line"; the generator power switches should be off. After connection, the generator may be activated, and the switches turned on when stable operation is obtained.

During high load operation of APU's, the power cables frequently heat excessively and the cable voltage drop is quite noticeable. Nearly all of the mobile electric power plants (MEPP's) have an output current capability well in excess of the current rating of the cables. Therefore, when supplying power to large loads, the current ratings of the cables must be considered. If the total load requirement exceeds the rating of the cable, the load should be reduced.

Mobile Electric Powerplants

NC-8A.—The NC-8A is a mobile, self-propelled, self-contained, electric powerplant utilized for servicing and starting rotary and fixed wing aircraft. The powerplant is designed to produce 60 kva of 400 Hz, 120/208 volt a-c power and 500 amperes at 28 volts d-c power continuously, or 750 amperes d-c power intermittently. Both a-c and d-c power may be supplied simultaneously for loads up to 48 kw.

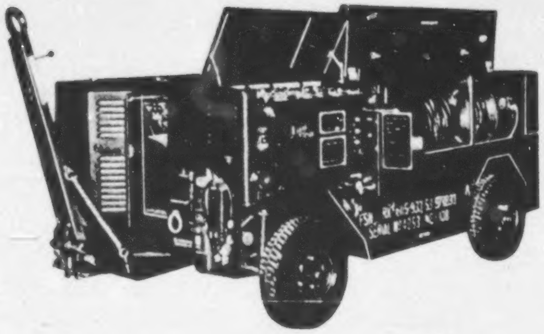
Power connections to the aircraft are made through 30 foot a-c and d-c cables that are stored on two spring loaded reels, mounted in the rear portions of the unit. The reels provide compact cable storage and automatic cable retraction when released from the lock position.

The powerplant is equipped with built-in safety devices that protect the load and itself from damage in the event the operation exceeds prescribed limits. Radio interference suppression componentry is incorporated in the powerplant to prevent interference with surrounding equipment and internal shielding prevents other equipment from interfering with the unit.

NC-10B.—The NC-10B MEPP (Mobile Electric Powerplant) is a diesel engine-driven mobile powerplant designed for shore based or shipboard facilities. It supplies regulated electrical power up to 90 kva at 0.8 power factor, 115/200 volts, 3-phase, 400 Hz for ground maintenance and service of helicopters and jet aircraft. A portion of the a-c power output is rectified to supply 28 volts d.c. at 750 amperes continously and 1,000 amperes intermittently for starting aircraft.

The self-contained MEPP, which may be towed up to 20 mph, requires no external, electrical, or mechanical sources of power. When self-propelled, it can move at 2 1/4 mph and can ascend a 15° incline at 1/2 mph. Controls for self-propulsion are located on the towbar. Electrical power controls and indicators are located on a control panel in the left front portion of the unit. Reel-mounted power cables are supplied along with a removable flood-light.

The powerplant components are mounted on a four-wheel trailer consisting of a welded steel chassis and running gear. Figure 8-4 shows the NC-10B MEPP. The running gear has a towbar used for vehicle towing and, when the unit is self-propelled, for front-wheel steering. A warning horn switch is actuated by a flapper (tang) in the towbar lunette eye. The warning horn sounds when powerplant towing is attempted but the rear wheel clutch drive pins are not



AT. 9

Figure 8-4.—NC-10B mobile electric powerplant.

disengaged. Towing with the pins engaged seriously damages the hydraulic propulsion motors. A handle, mounted on the towbar, controls forward and reverse movement of the self-propelled powerplant. When it is not towing or steering the NC-10B, the spring-loaded towbar returns to the upright position and applies the hydraulic brakes of the two rear wheels. The brakes are also applied by means of a cable-operated handbrake lever and by inertial force when the towed unit slows down.

The NC-10B is furnished with three 30-foot output cables, two for a.c. and one for d.c. Each cable is provided with a suitable connector which mates with the aircraft and is attached to a separate spring-return cable reel equipped with an automatic ratchet which holds the cable at any extended length. Cables are mounted in the same order as the output switches on the control panel (fig. 8-5). The two cables nearest the control panel supply a.c. and the farthest cable supplies d.c. The a-c cable nearest the control panel and the d-c cable are compensated for voltage drop attributed to cable length.

The NC-10B is equipped with several fault-sensing circuits which, depending upon the nature of the fault, either shut down the engine or discontinue the electric power output and

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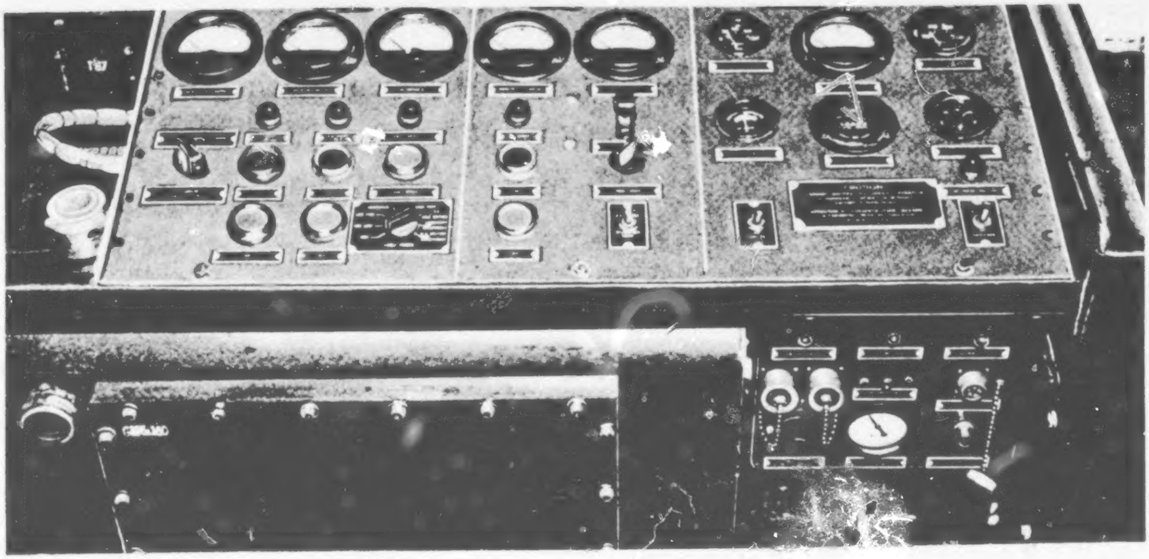


AT. 10

Figure 8-5.—Control and gage panels.

bring the engine to idle. Monitored engine faults are: high coolant temperature, low lube oil pressure, overspeed, and low fuel supply (one-half-hour operating time remaining). Any of these faults will energize the engine fuel and air-supply shutoff solenoids and thus shut down the diesel engine. Other faults which discontinue electrical output, open electrical contactors, and bring the engine to idle are: overvoltage or undervoltage, overfrequency or underfrequency, and d-c output overvoltage.

Instructions for the operation of the powerplant are presented in the MEPP handbook (NA 19-45-8).

NC-12 AND NC-12A.–The NC-12 and NC-12A are diesel engine-driven powerplants, designed to supply 125 kva at 115/200 volts, 3-phase, 400 Hz for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the generated electric power is rectified to supply 28 volts d.c. at 750 amperes (1,000 amperes intermittent) for aircraft starting. These units utilize dual power output circuits which make them capable of simultaneously delivering electric power for two P-3A aircraft.

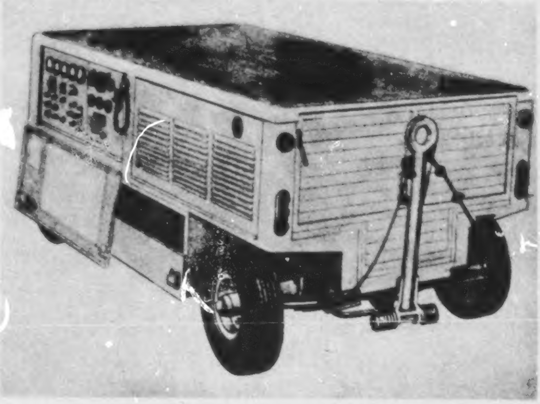
The powerplants and components are mounted on a four-wheel trailer, equipped with mechanical front wheel brakes which are actuated by a hand lever or the spring-loaded towbar. These units do not come equipped with self-propelled features; they must be towed.

The NC-12 and NC-12A are similar except the NC-12 was designed for shore duty operation, while the NC-12A was designed for either carrier or shore-based use. The electrical characteristics are identical. Figure 8-6 depicts the NC-12A.

The technician will come in contact with many new types of powerplants such as the NC-8 series, NC-10 series, and NC-12 series, which will eventually replace the older plants such as the NC-5, NC-6, and NC-7 series.

(NOTE: Most naval air stations and activities have training courses available to provide instruction in the use and operation of mobile powerplants. Only licensed operators should operate this type equipment.)

Table 8-1 shows a comparison of the major characteristics of the mobile electric powerplants discussed in the preceding paragraphs, as well as some older types still in common usage.



AT. 61

Figure 8-6.–Mobile electric powerplant, type NC-12A.

AIRBORNE AUXILIARY POWER UNITS

As discussed under the heading P-3C electrical system, some of the larger aircraft are equipped with auxiliary power units (APU). These may be installed at different locations on different aircraft. They are used to furnish electrical power when engine-driven generators are not operating or when external power is not available. The APU is utilized to furnish power since excessive battery usage must be avoided when possible. The power output from the APU provides a constant voltage at a constant frequency, which is advantageous since the APU is not dependent on aircraft engine rpm.

In addition to driving a generator, the gas turbine type APU may also provide compressed air to start engines (using the pneumatic starting system) and for air conditioning, thereby making the aircraft independent of the need of ground power units to carry out its mission. (See figure 8-7.)

Auxiliary powerplant logbooks must be kept on each powerplant. The operator of the powerplant is responsible for entering the operating time in the log each time the unit is used.

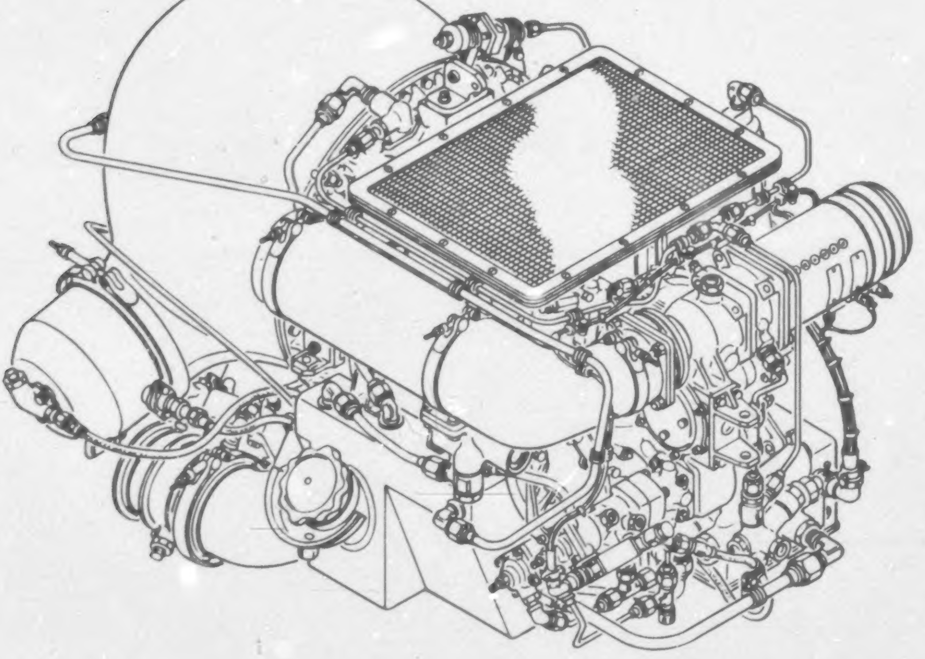
DECKEDGE POWER

The primary function of the deckedge electrical power system installed on aircraft carriers is

Table 8-1. Characteristics of mobile electric powerplants.

Type	Methods of propulsion	Generator drive	Operating environment	Power ratings		Starting power		Service power	
				d.c.	a.c.	Jet	Recip.	Jet	Recip.
*NC-5, *NC-5A, *NC-5B	Self-propelled gasoline engine vehicle	Main vehicle engine	Shore based only	28/35v 200/500a 1000a int	115/200v 400 Hz, 3ϕ 30/45 kva	d.c. only	d.c. only	a.c. d.c.	a.c. d.c.
NC-6, NC-6A	Towed trailer	Gasoline engine	Shore based only	28.5v 200a 32/45 kw	120/208v 400 Hz, 3ϕ 30 kva	DNA	DNA	a.c. d.c.	a.c. d.c.
*NC-7, *NC-7A, *NC-7B, *NC-7C	Towed trailer, some models self-propelled	Gasoline engine	Shore based only	28.5v 750a 1000a int 45 kw	115/200v 400 Hz, 3ϕ 35 kva 0.75 PF	d.c. only	d.c. only	a.c. d.c.	a.c. d.c.
NC-8A	Self-propelled electric motor	Diesel engine	Shore or carrier based	28v 500a 750a int	120/208v 400 Hz 60 kva	d.c. only	d.c. only	a.c.	a.c.
NC-10	Towed trailer	Diesel engine	Shore or carrier based	28v 750a 1000a int	115/200v 400 Hz 90 kva	d.c. only	d.c. only	a.c. d.c.	a.c. d.c.
NC-10A	Towed trailer or self-propelled	(same)	(same)	(same)	(same)	(same)	(same)	(same)	(same)
NC-10B	(same)	(same)	(same)	(same)	(same)	(same)	(same)	(same)	(same)
NC-12	Towed trailer	Diesel engine	Shore based only	28v 750a 1000a int 45 kw	115/200v 400 Hz 125 kva	d.c. only	d.c. only	a.c. d.c.	a.c. d.c.
NC-12A	(same)	(same)	Shore or carrier based	(same)	(same)	(same)	(same)	(same)	(same)

*Being phased out of service.



AT. 11

Figure 8-7.—Gas turbine type APU.

to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight and hangar decks.

The 28-volt d.c. is supplied by motor-generators or rectified a.c. from remote a-c generators.

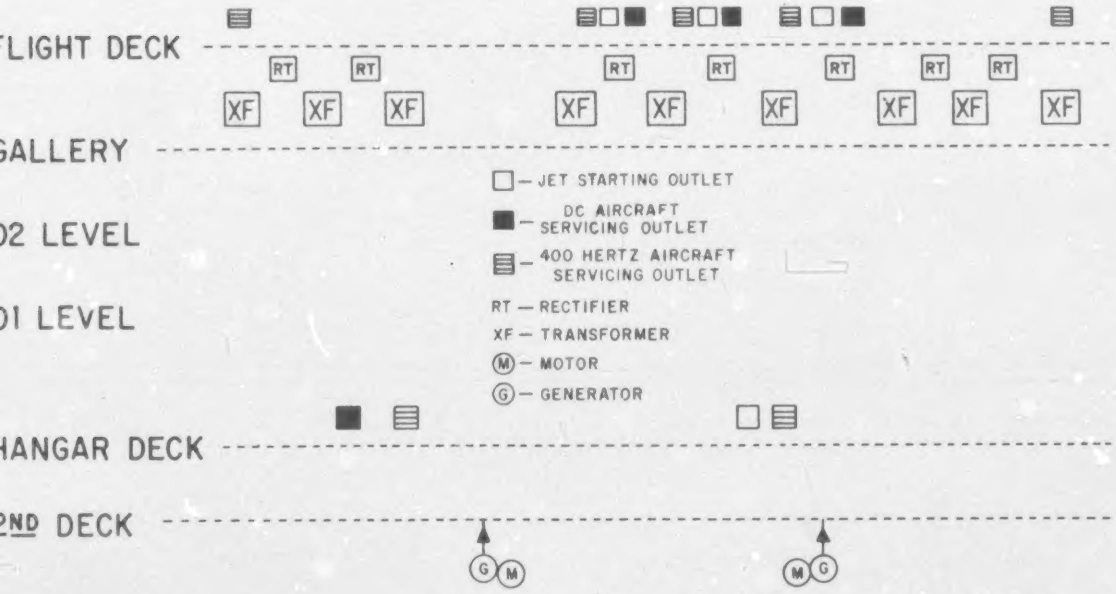
The 400 Hz, 3-phase a-c servicing voltage is usually supplied by these same a-c generators through stepdown transformers. Figure 8-8 shows a diagram of an electrical system which may be found on a modern carrier. The deckedge power may be supplied by service outlets at the edge of the flight deck or from recesses in the flight deck. All systems have standard remote control switches, service outlet boxes, and portable cables. Figure 8-9 shows a typical deckedge installation.

Although there are some variations between carriers of different classes and aircraft of different models, this discussion and the associated figures represent a typical example. For explicit details concerning a specific installation, check the deckedge station and its power cables.

The d-c service outlet box contains two male plugs. One is rectangular in shape and the other is oval. The rectangular plug provides servicing power and the oval plug provides starting power for aircraft with electrical starters.

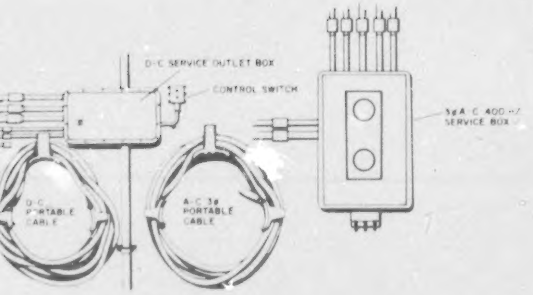
The aircraft is equipped with an oval-shaped plug for applying d-c servicing power and a rectangular-shaped six-pin plug for applying 3-phase, 400 Hz, a-c servicing power. Power is applied to the aircraft by connecting the portable cables between the deckedge and aircraft plugs. To obtain d-c servicing power, the oval end of the portable cable is connected to the oval plug in the aircraft and the opposite (rectangular) end is connected to the rectangular deckedge plug.

To obtain 3-phase, 400 Hz, a-c service power,


LIGHT DECK
RT
XF
ALLERY
02 LEVEL
01 LEVEL
HANGAR DECK
2ND DECK
☐ — JET STARTING OUTLET
■ — DC AIRCRAFT SERVICING OUTLET
▤ — 400 HERTZ AIRCRAFT SERVICING OUTLET
RT — RECTIFIER
XF — TRANSFORMER
Ⓜ — MOTOR
Ⓖ — GENERATOR
G
M

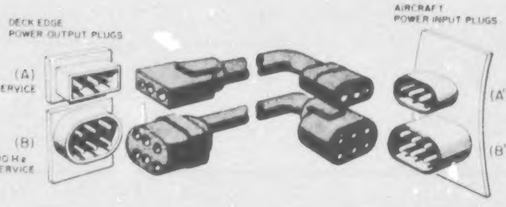
AT. 65

Figure 8-8.—Deckedge electrical system.


D-C SERVICE OUTLET BOX
CONTROL SWITCH
3φ A-C 400 HZ SERVICE BOX
D-C PORTABLE CABLE
A-C 3φ PORTABLE CABLE

AT. 66

Figure 8-9.—Typical deckedge installation.


DECK EDGE POWER OUTPUT PLUGS
AIRCRAFT POWER INPUT PLUGS
(A) D-C SERVICE
(B) 3φ 400 Hz A-C SERVICE
(A')
(B')

AT. 67

Figure 8-10.—D-c and a-c power cables and plugs.

e portable a-c plug is connected to the aircraft nd the opposite end to deckedge a-c service ower box. The ends of the a-c portable cable e interchangeable.

Figure 8-10 illustrates how these connections ay be made. To obtain d-c servicing power to ne aircraft, connect the cable from A to A′; to otain a-c service power connect it from B to B′.

The a-c service power is usually provided at the same station as the d-c power. The cable is usually permanently attached to the service outlet box. Although its plug is rectangular, there is no danger of connecting it to the d-c service power receptacle as the size and number of pins are not the same.

Care should be exercised when connecting auxiliary power cables to the aircraft. The cables are heavy, and damage to the aircraft may result if there is not sufficient slack in the cables.

GROUND COOLING SYSTEMS

The purpose and need for ground cooling will vary with type of aircraft and climatic conditions. When repairing high-voltage equipment aboard large aircraft in a tropic zone, ground cooling of the aircraft cabin reduces the hazard of shock due to clothing being wet with perspiration. It may also prevent shorting of components by falling perspiration.

An additional reason for using ground cooling equipment, even in temperate zones, is the fact that electronic equipment produces large quantities of heat. This heat must be dissipated or the equipment would achieve temperatures that could cause damage and create a fire hazard. When the aircraft is airborne, various means are used to accomplish the required cooling. Some electronic equipments have fans built in for cooling. Others generate so much heat that a blast of air from outside the aircraft must be used. Some large magnetrons are liquid cooled the liquid, in turn, is cooled by air directed over a radiator.

When a large quantity of air is required for cooling, a common source for the air is the aircraft's ventilation system. However, line maintenance, ground operational checks, and functional checks are usually performed without the aircraft's ventilation system operating, since this system is driven by the aircraft engines. Therefore, a substitute air supply must be provided for the air distribution system.

The air distribution system illustrated in figure 8-11 consists of two subsystems. One subsystem controls and distributes the incoming fresh air supply; the other controls exhaust airflow through electronic racks and tactical crew station cabinets to the atmosphere. The fresh air distribution subsystem is designed to use fresh, temperature-controlled air from two engine-driven cabin air compressors. An alternate source of unconditioned fresh air, called the auxiliary ventilation system, may be used in flight to supplement the temperature-controlled air from the cabin air compressors.

The auxiliary ventilation system receives air from a ram air inlet. This inlet and a ground air connection are adjacent to one another in the nosewheel well and connect to a common duct. This duct connects to the duct which normally carries air from the cabin air cycle cooling system to the cabin air riser (vertical duct). The air from either of these alternate fresh air sources is routed the same as air coming from the cabin air cycle cooling system. Therefore, the ground connection permits the output from a mobile air conditioner to be routed through the duct which normally carries air from the cabin air cycle cooling system. This is particularly desirable for line maintenance purposes.

ACM-2905-F22

The ACM-2905-F22 is a mobile aircraft air conditioner that is capable of delivering 21.9 tons of refrigeration at 2,500 cfm (cubic feet per minute). A ton of refrigeration is the amount of cooling resulting from the absorption of enough heat to melt a ton of ice at 32° F in a 24-hour period. This is equivalent to a cooling capacity of approximately 12,000 Btu per hour.

The air conditioning unit consists of a 7-cylinder, 40-ton radial compressor directly connected to a 150-hp internal combustion engine; large cooling coils; and an evaporative condenser. (See fig. 8-12.) The engine uses conventional automotive type electrical starting and battery charging equipment.

The unit is housed in a 12-foot truck body and is controlled from a simple panel located on the outside of the truck for ease of operation. (See fig. 8-13.)

A built-in safety system cuts off the ignition to the air-conditioning unit whenever the following conditions occur:

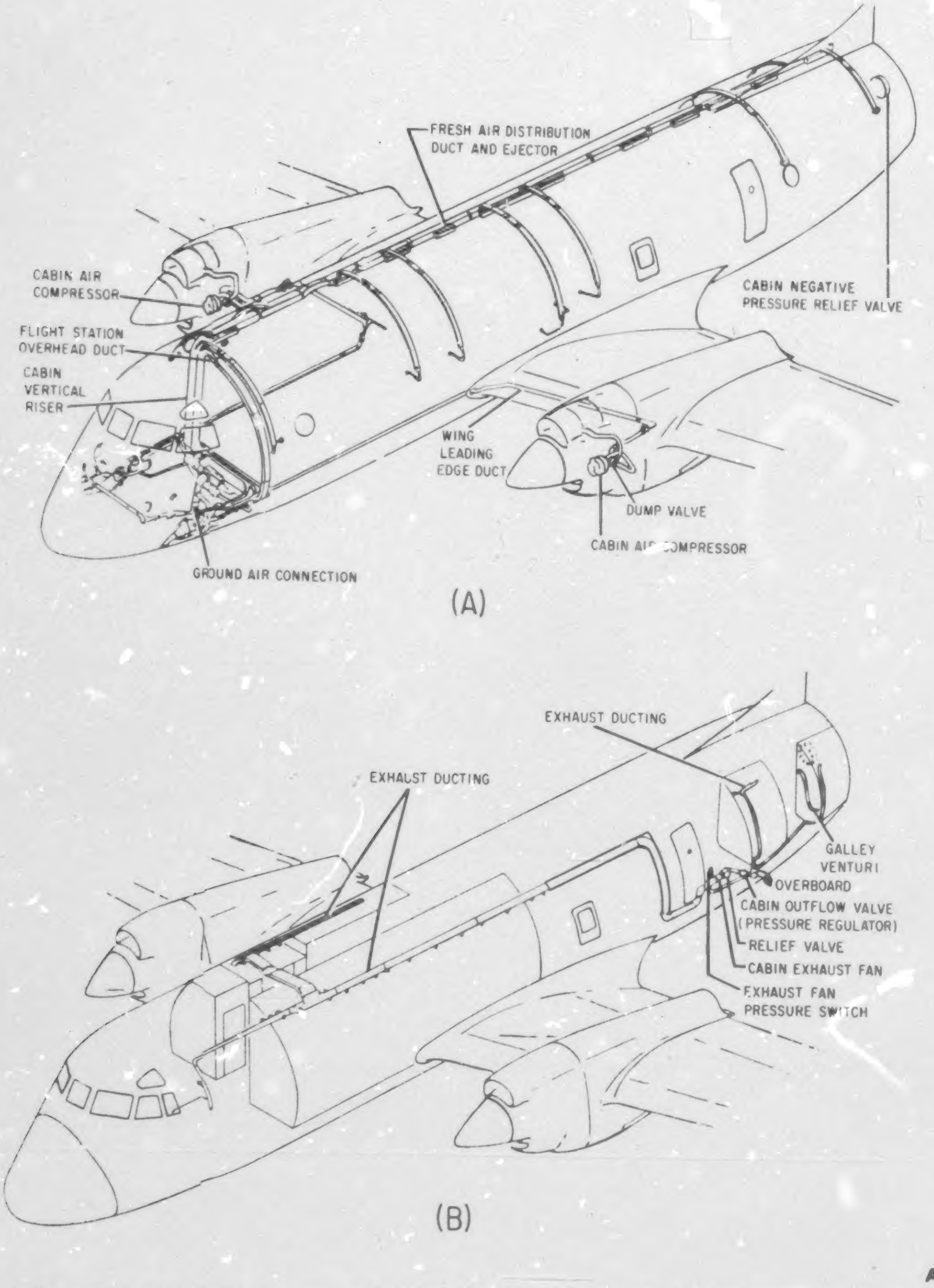
1. Loss of engine oil pressure
2. Engine water temperature too high.
3. Compressor-suction pressure too low.
4. Compressor discharge pressure too high.

Should any of these conditions occur, an alarm bell will sound, a red light on the control panel will be illuminated, and the engine will automatically shut down.

The control panel, mounted in the left side of the unit, contains the following instruments and controls:

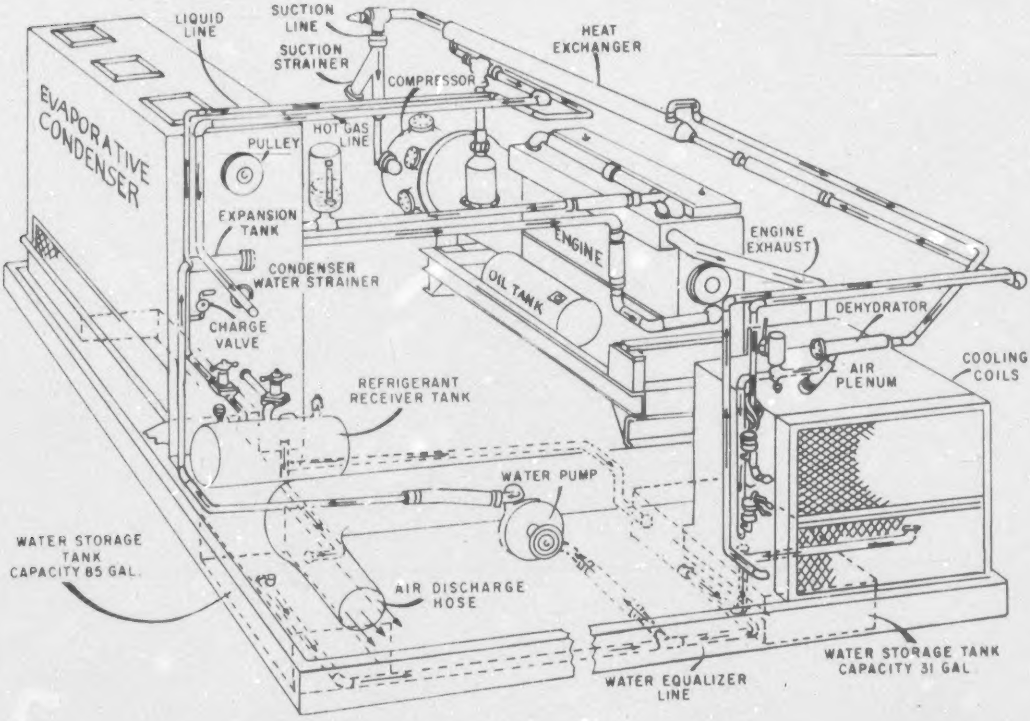
1. Panel lights and switch. Two panel lights are supplied to provide illumination for the control panel.

2. Interior light switch and pilot light. This switch is provided to operate lights situated at


FRESH AIR DISTRIBUTION DUCT AND EJECTOR
CABIN AIR COMPRESSOR
FLIGHT STATION OVERHEAD DUCT
CABIN VERTICAL RISER
CABIN NEGATIVE PRESSURE RELIEF VALVE
WING LEADING EDGE DUCT
DUMP VALVE
CABIN AIR COMPRESSOR
GROUND AIR CONNECTION
(A)
EXHAUST DUCTING
EXHAUST DUCTING
GALLEY VENTURI
OVERBOARD
CABIN OUTFLOW VALVE (PRESSURE REGULATOR)
RELIEF VALVE
CABIN EXHAUST FAN
EXHAUST FAN PRESSURE SWITCH
(B)

AT. 68

Figure 8-11.—Air distribution system of an aircraft. (A) Inlet air system; (B) exhaust air system.


LIQUID LINE
SUCTION LINE
SUCTION STRAINER
HEAT EXCHANGER
COMPRESSOR
EVAPORATIVE CONDENSER
HOT GAS LINE
PULLEY
EXPANSION TANK
ENGINE
ENGINE EXHAUST
CONDENSER WATER STRAINER
OIL TANK
DEHYDRATOR
CHARGE VALVE
AIR PLENUM
COOLING COILS
REFRIGERANT RECEIVER TANK
WATER PUMP
WATER STORAGE TANK CAPACITY 85 GAL.
AIR DISCHARGE HOSE
WATER STORAGE TANK CAPACITY 31 GAL
WATER EQUALIZER LINE

AT. 70

Figure 8-12.—Air-conditioning unit, functional diagram.

other points in the installation. The green pilot light indicates when the interior lights are on.

3. Safety release switch. This is a push-button switch which is used to remove the safety controls from the circuit. Should a shutdown occur due to excessively high water temperature, it might be necessary to hold this button in while starting the engine after the cause of the shutdown has been corrected.

4. Key ignition switch. This switch prevents unauthorized persons from attempting to operate the machine. When the switch is turned off, the entire electrical system is disconnected and the starting motor cannot be operated.

5. Tachometer. The electric tachometer indicates the engine speed in revolutions per minute.

6. The ammeter. The ammeter indicates the rate of charge or flow of electric current being supplied to the battery by the generator, or the rate of discharge from the battery.

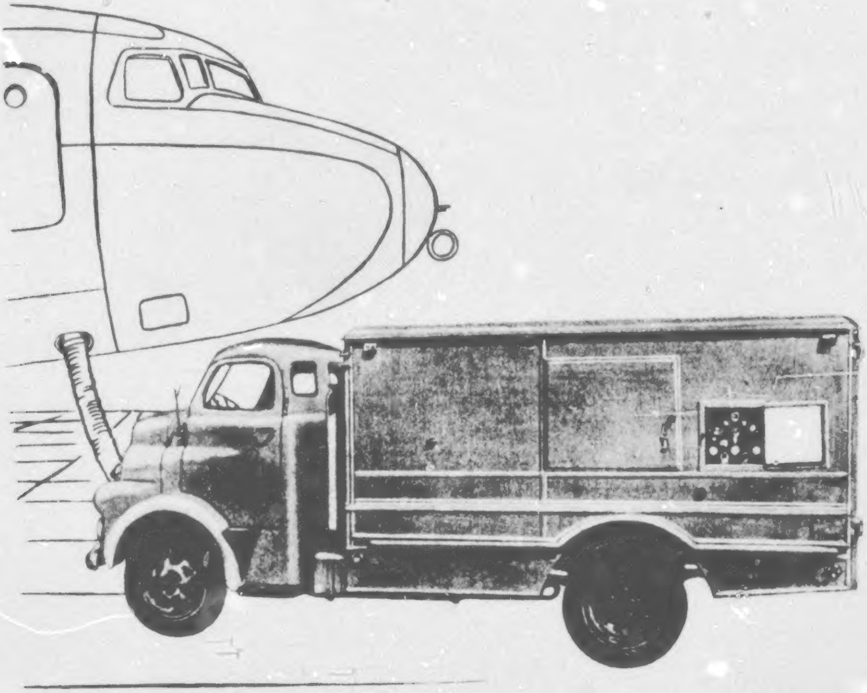
7. Oil pressure gage. The oil pressure gage indicates the pressure of the engine oil, not the amount of oil in the crankcase.

8. Water temperature gage. The temperature gage indicates the temperature of the cooling system of the engine (not the air conditioner).

9. Starting button. Pressing the button, after the key switch is turned on, completes the circuit between the battery and starting motor to crank the engine.

10. Choke control. Pulling the choke out supplies a richer mixture for starting when the engine is cold.

11. Vernier type throttle control. The throttle is equipped with a locking device to hold the control in any desired position.



AT.71

Figure 8-13.—Air-conditioning truck mounting and control panel.

12. Fuel tank gage. The fuel gage is electrically operated and is connected to the fuel tank sensing unit. The gage indicates the level of gasoline in the tank and will only register after the ignition switch is turned on.

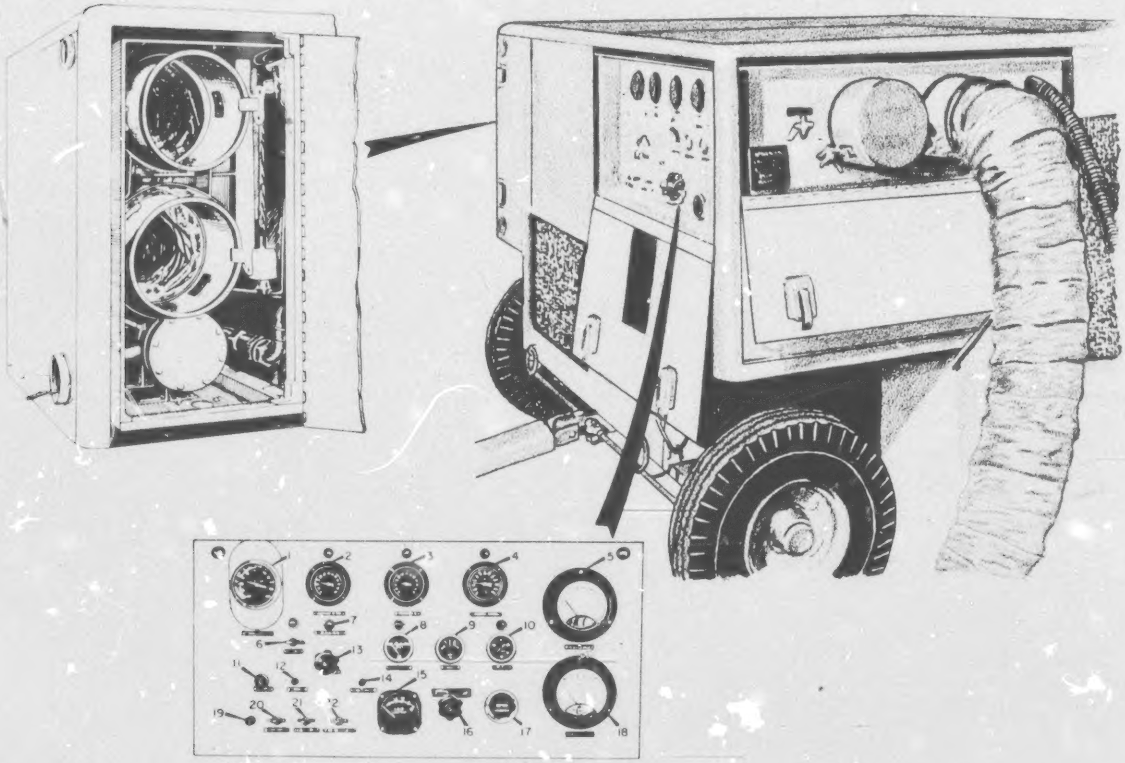
13. Evaporator-condenser water tank gage. Operating similarly to the above, this gage indicates the water level in the evaporative condenser supply tank.

14. Winter switch. This switch is used to operate a solenoid valve in the refrigerant line. In winter, when it is desired to operate the engine without refrigeration, the switch is to be set at the OFF position. For normal operation, however, the switch is to be left ON.

15. Refrigeration gages. These three instruments (reading from left to right when facing the control panel) are: Compressor suction pressure gage, compressor oil pressure gage, and compressor discharge pressure gage.

NR-3

The NR-3 is a trailer-mounted, Freon cycle, 120-hp, engine-driven mobile air-conditioning unit. (See fig. 8-14.) This unit is completely self-sustaining and carries enough fuel and water to provide 4 hours of continuous operation. A lunette eye, with a shock control device, is attached to the end of a steerable tow bar and will allow the air conditioner to be towed up to speeds of 40 mph on paved surfaces. A tow bar retainer allows the tow bar to be stowed in the vertical position when not in use. A parking brake provides a means of securing the fully loaded unit on grades up to 35 percent.



AT. 72

Figure 8-14.—NR-3 air conditioner.

This air-conditioning unit supplies cool, moisture-free air to the cabin conditioning and cooling equipment systems during ground checkout and testing of an aircraft's various systems. The unit is capable of delivering 294,000 Btu (24.5 tons gross) of conditioned air. This produces 100 pounds of airflow, at a pressure of 3 pounds per square inch, throughout a range in ambient temperatures from 10° C (50° F) to 43° C (133° F) when measured at sea level. The equipment is designed to operate at altitudes up to 5,000 feet above sea level.

NR-10

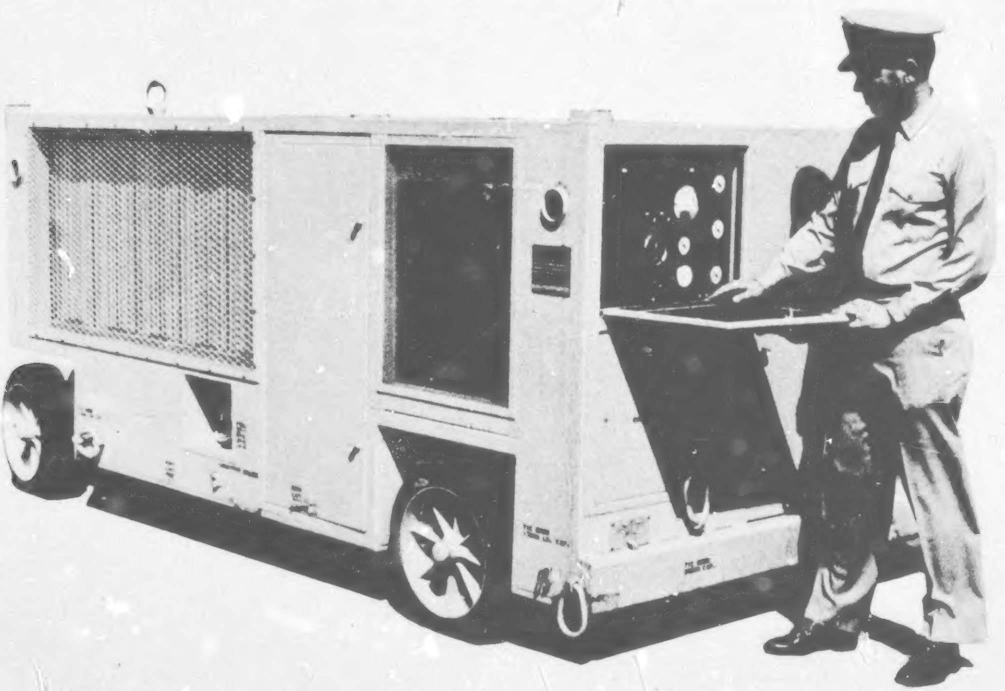
The purpose and the basic operation of the NR-10 are the same as the NR-3; however, the NR-10 (fig. 8-15) is a later model. This mobile air conditioner is a trailer mounted, self-contained unit. It has a cooling capacity of 19 tons, utilizing a 6-cylinder open type refrigerant compressor.

The air conditioner is designed to provide cooling, ventilation, dehumidification, and filtration of air for electronic equipment.

For further information on the NR-10, refer to NA 19-60-76.

MULTIPURPOSE SERVICING UNIT RCPP 105

The AiResearch RCPP 105 is a gas turbine-driven power and refrigeration aircraft ground support unit furnished to the Navy in three different configurations. It is used primarily in



AS. 219

Figure 8-15.—NR-10 air conditioner.

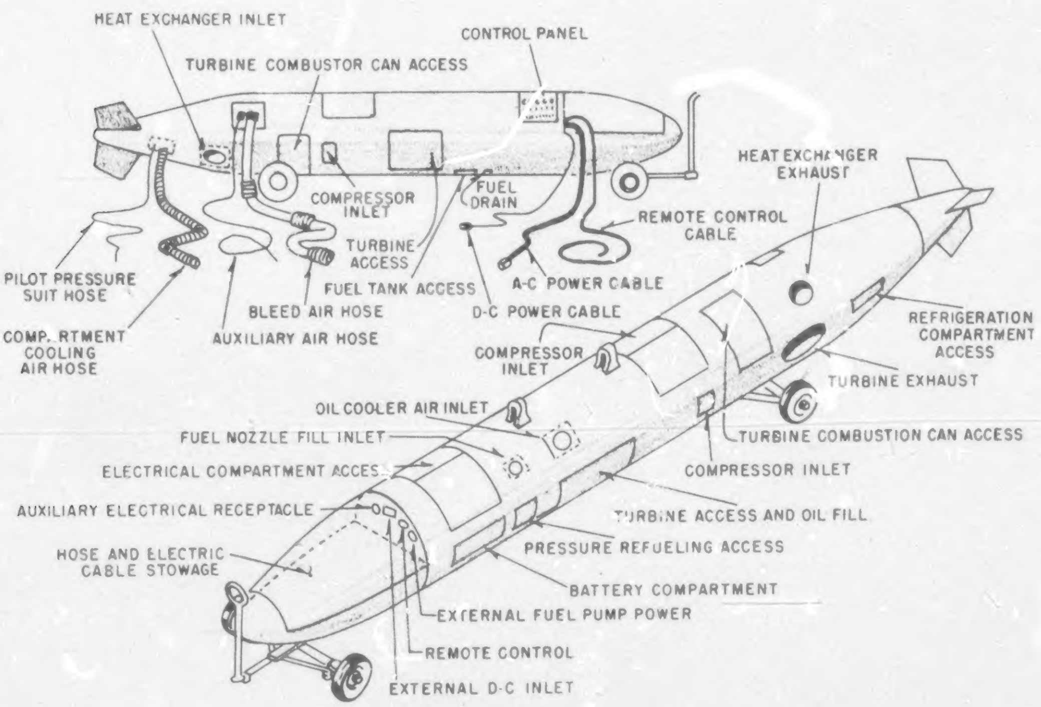
support of the RA-5C and F-4B aircraft. All three arrangements employ basically the same system, using a small gas turbine to supply electric power and air for refrigeration, main aircraft engine starting, and pilot suit pressurization.

(NOTE: Electric power is generated by an air-driven turbine.)

The RCPP 105 (one of the three available models) is mounted in a 22-foot long aerodynamic pod for air transportation as an aircraft external store. On the RA-5C, the pod is transported under the wing; on the F-4B, it is carried under the fuselage. A cradle type towable trailer is provided for ground movement of the unit. (See fig. 8-16.)

The RCPT 105 is mounted on a self-propelled, low-silhouette (38 inches from the ground) trailer.

The tractor unit is similar to the RCPT 105 except that the turbine-driven unit is mounted on a diesel tractor.


HEAT EXCHANGER INLET
CONTROL PANEL
TURBINE COMBUSTOR CAN ACCESS
HEAT EXCHANGER EXHAUST
COMPRESSOR INLET
FUEL DRAIN
REMOTE CONTROL CABLE
TURBINE ACCESS
PILOT PRESSURE SUIT HOSE
FUEL TANK ACCESS
A-C POWER CABLE
BLEED AIR HOSE
D-C POWER CABLE
COMPARTMENT COOLING AIR HOSE
AUXILIARY AIR HOSE
REFRIGERATION COMPARTMENT ACCESS
COMPRESSOR INLET
TURBINE EXHAUST
OIL COOLER AIR INLET
FUEL NOZZLE FILL INLET
TURBINE COMBUSTION CAN ACCESS
ELECTRICAL COMPARTMENT ACCESS
COMPRESSOR INLET
AUXILIARY ELECTRICAL RECEPTACLE
TURBINE ACCESS AND OIL FILL
PRESSURE REFUELING ACCESS
HOSE AND ELECTRIC CABLE STOWAGE
BATTERY COMPARTMENT
EXTERNAL FUEL PUMP POWER
REMOTE CONTROL
EXTERNAL D-C INLET

AT. 73

Figure 8-16.—RCPP 105, showing external connections.

CHAPTER 9

AIRBORNE COMMUNICATIONS EQUIPMENT

COMMUNICATIONS RECEIVERS AND TRANSMITTERS

One of the duties of a technician may be to operate and maintain many different types of aircraft communication equipments. These equipments differ in many respects; however, in other respects they are similar. It is beyond the scope of this training manual to present information that relates to all of the many different equipments; therefore, only representative sets are discussed.

Distinctive features of naval airborne communications equipment include automatic tuning, subassembly and modular types of construction, shock mounting of major units, and pressurization, as well as the electronic components and circuitry employed.

Automatic tuning, which makes possible rapid selection of preset channels, is used in most modern naval airborne communication systems. This feature is essential because channel changes must be made accurately and quickly. Since the automatic system provides great simplicity of control, the entire operation is usually accomplished by means of a single dial.

The use of shock mounting is required because of vibration and the extreme physical forces present in normal operation in aircraft. The construction of electronic equipment in subassemblies and modules simplifies maintenance and repair. It permits the removal and replacement of sections containing defective or malfunctioning parts without dismantling the entire equipment.

All radio communication equipments, whether military or civilian, are designed for operation within certain well-defined frequency limits. In this chapter the terms used in reference to frequency bands designate major portions of the radio spectrum. The designations and abbreviations are those in general use.

GENERAL PURPOSE RECEIVER AN/ARR-41

Radio Receiving Set AN/ARR-41, consisting of the receiver R-648/ARR-41 and its mounting, is a radio receiver that finds general application in naval aircraft. It is a superheterodyne receiver capable of receiving RF signals from 190 kHz to 550 kHz and from 2 MHz to 25 MHz, covered in five frequency bands. A mechanical type counter, located on the front panel of the receiver, indicates the frequency (in megahertz) of the received signals. It can receive signals which are of the AM, unmodulated CW, or frequency shift keyed types. Accurate frequency calibration is obtained through a built-in circuit consisting of a 500 kHz crystal-controlled oscillator and a multivibrator. Construction is of the subassembly design.

The Maintenance Instructions Manual for the receiver presents in detail the theory and operation of the receiver, the maintenance, test, and alinement procedures and specifications, and the complete list of test equipment required. Only a brief summary of the theory of operation of the ARR-41 is presented in this chapter.

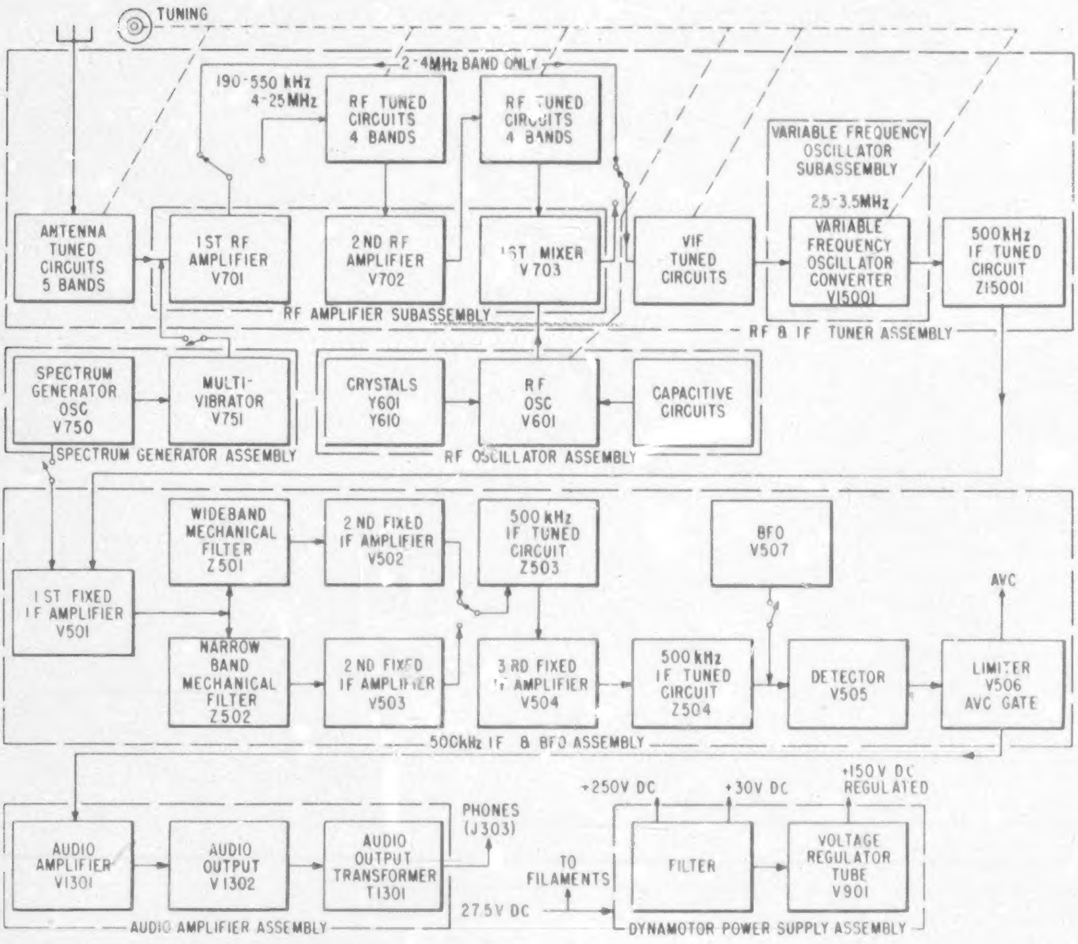
Theory of Operation

This receiver employs double conversion; that is, all received RF signals (except for band 2) are first converted to a variable IF, amplified, and then converted to a fixed IF. (Band 2 covers the range of 2 megahertz to 4 megahertz; signals within this band are shunted around the first converter, or mixer.) Some of the benefits obtained by double conversion are high gain and sensitivity.

For CW reception the set employs a beat frequency oscillator (BFO), with a control for variable pitch or tone. A CW signal contains no modulation, so a separate oscillator must be built into the receiver to beat with the incoming IF to produce a signal that when detected and amplified is within audio range.

Figure 9-1 is a block diagram of the receiver. Reference to this diagram, in connection with the discussion that follows, simplifies the explanation of the receiver's operation. Particular attention should be paid to the direction of the arrows.

The incoming RF signal is received by the antenna and applied to one of five tuned circuits, depending upon the band of reception. The signal is then applied to the grid of the first RF amplifier, V701, for amplification. After the


TUNING
2-4MHz BAND ONLY
190-550 kHz
4-25MHz
RF TUNED CIRCUITS 4 BANDS
RF TUNED CIRCUITS 4 BANDS
VARIABLE FREQUENCY OSCILLATOR SUBASSEMBLY
2.5-3.5MHz
ANTENNA TUNED CIRCUITS 5 BANDS
1ST RF AMPLIFIER V701
2ND RF AMPLIFIER V702
1ST MIXER V703
VIF TUNED CIRCUITS
VARIABLE FREQUENCY OSCILLATOR CONVERTER V15001
500kHz IF TUNED CIRCUIT Z15001
RF AMPLIFIER SUBASSEMBLY
RF & IF TUNER ASSEMBLY
SPECTRUM GENERATOR OSC V750
MULTI-VIBRATOR V751
CRYSTALS Y601 Y610
RF OSC V601
CAPACITIVE CIRCUITS
SPECTRUM GENERATOR ASSEMBLY
RF OSCILLATOR ASSEMBLY
WIDEBAND MECHANICAL FILTER Z501
2ND FIXED IF AMPLIFIER V502
500kHz IF TUNED CIRCUIT Z503
BFO V507
1ST FIXED IF AMPLIFIER V501
AVC
NARROW BAND MECHANICAL FILTER Z502
2ND FIXED IF AMPLIFIER V503
3RD FIXED IF AMPLIFIER V504
500kHz IF TUNED CIRCUIT Z504
DETECTOR V505
LIMITER V506 AVC GATE
500kHz IF & BFO ASSEMBLY
+250V DC
+30V DC
+150V DC REGULATED
PHONES (J303)
AUDIO AMPLIFIER V1301
AUDIO OUTPUT V1302
AUDIO OUTPUT TRANSFORMER T1301
TO FILAMENTS
FILTER
VOLTAGE REGULATOR TUBE V901
27.5V DC
AUDIO AMPLIFIER ASSEMBLY
DYNAMOTOR POWER SUPPLY ASSEMBLY

AT. 292

Figure 9-1.—Block diagram of Radio Receiver R-648/ARR-41.

first stage of RF amplification, frequencies within the range of bands 1, 3, 4, and 5 are applied through tuned circuits to the second RF amplifier and then through more tuned circuits to the first mixer, V703. The function of the first mixer is to heterodyne the output of the RF oscillator, V601, with the incoming RF and produce a variable IF of 2 MHz to 4 MHz. Band 2 frequencies are 2 MHz to 4 MHz without heterodyning and therefore are switched around the second RF amplifier and first mixer circuits. (The switches in the block diagram are shown in band 2 position.)

At this point, any signal, regardless of the original frequency, is within the range of 2 MHz to 4 MHz and is applied through the variable IF tuned circuits to the variable frequency oscillator converter, V15001. Mixer V15001 heterodynes the variable IF 2 MHz to 4 MHz signal with a locally generated 2.5 MHz to 3.5 MHz signal, producing an output of 500 kHz, the fixed intermediate frequency.

The 500 kHz signal is applied to the grid of V501 for first IF amplification. This output passes through either a broadband or narrowband mechanical filter and through one of two second IF amplifiers. Bandwidth selection (broad or narrow) depends upon the setting of the emission switch. The IF signal is then applied through another tuned circuit to the grid of the third IF amplifier, V504, the plate circuit of which contains the IF tuned circuit Z504. Tuned circuit Z504 couples the output of IF amplifier V504 to the detector tube V505. The functions of V505 are to recover the modulation component of the IF signal (detection) and to produce a negative voltage proportional to the carrier level for automatic volume control (AVC).

The BFO may be switched into the detector input by operation of the emission switch to the CW or CW SHP (CW Sharp) positions. In this manner a beat note is produced with the 500 kHz IF signal, which is a variable tone to be used for CW reception. Output from the detector is applied to V506, the limiter and AVC gate. One-half of dual diode V506 functions as an AVC gate control and prevents application of AVC voltage to the various amplifiers until full receiver sensitivity has been reached. The other half of V506 is a noise limiter which suppresses undesired noise pulses. The output of V506 is an audio voltage proportional to the modulation of the incoming RF signal. Audio amplifier V1301 and audio output V1302 serve to amplify the audio signal. Phone jack 1303 is connected to audio output transformer T1301, and is available on the front panel of the receiver.

The spectrum generator consists of a crystal-controlled oscillator and a multivibrator divider circuit. The crystal-controlled oscillator, V750, serves to produce an accurate 500 kHz signal. The 500 kHz signal is applied to the grid of the first IF amplifier, V501, and to one plate and grid of the multivibrator divider, V751. The multivibrator fires on every fifth input pulse and produces an output, to the first RF amplifier, of 100 kHz. This 100 kHz output signal is rich in harmonics and allows the RF circuits to tune to a particular harmonic, depending upon the resonant frequency of the tuned circuits. A beat note is produced as a result of heterodyning the 500 kHz signal applied to the first IF amplifier with the selected harmonic of the multivibrator. This beat note is heard when the receiver frequency is varied around the selected multivibrator harmonic and the correct receiver frequency is known on the basis of the counter reading. The counter may then be set to the exact 100 kHz multiple and calibration is completed.

Operation

Complete details regarding the operating procedures of the AN/ARR-41 are contained in the Maintenance Instructions Manual. This discussion is presented only to provide a few details concerning capabilities of the receiver.

The emission selector switch has two positions which are used when noise interferes with reception of voice or CW signals. By switching to either of these two sharp positions, a narrowband filter is inserted into the IF circuit to reduce the effective noise level.

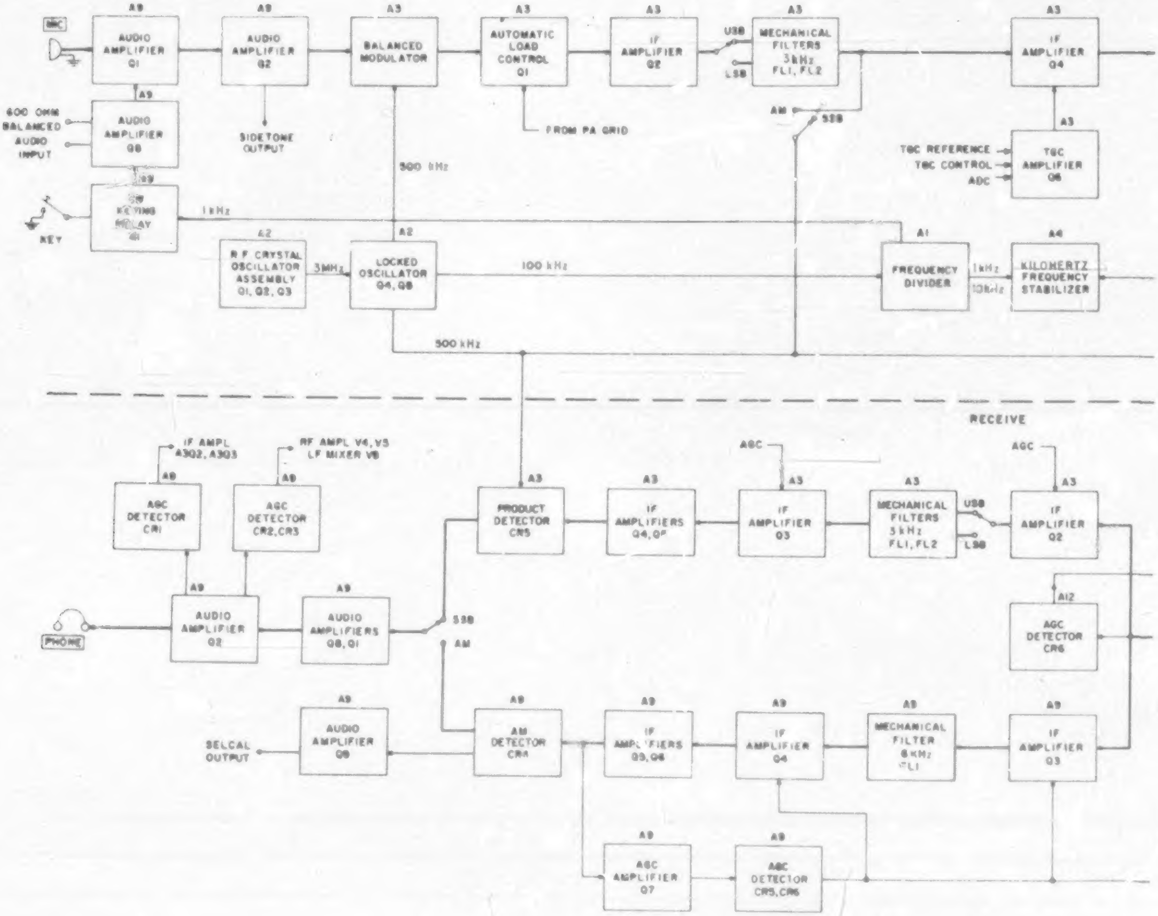
Selected frequency is indicated on three counter dials. Selected band is indicated on a fourth dial located immediately to the left of the frequency counters. Interpolation to within 0.1 kHz is made possible by the arrow located to the right of the right-hand counter.

Calibration and Maintenance

Calibration and maintenance procedures and specifications are contained in the Maintenance Instructions Manual.

SINGLE SIDEBAND HF TRANSCEIVER AN/ARC-94

Radio Set AN/ARC-94 provides facilities for communication between aircraft, and between aircraft and fixed or mobile ground communications stations. The AN/ARC-94 transmits and receives communications in the high-frequency (HF) band and can operate above 28 megahertz. The set includes Radio Receiver-Transmitter RT-648/ARC-94, Radio Set Control C-3940/ARC-94, and Mounting MT-2641/ARC-94. The RT unit is of modular construction for ease of maintenance. In addition to the set components, the complete aircraft installation requires a headset, microphone, key, antenna coupler, and antenna.


MIC
A9
AUDIO AMPLIFIER Q1
A9
AUDIO AMPLIFIER Q2
A3
BALANCED MODULATOR
A3
AUTOMATIC LOAD CONTROL Q1
A3
IF AMPLIFIER Q2
USB
LSB
A3
MECHANICAL FILTERS 3kHz FL1, FL2
A3
IF AMPLIFIER Q4
A9
600 OHM BALANCED AUDIO INPUT
AUDIO AMPLIFIER Q8
SIDETONE OUTPUT
FROM PA GRID
AM
SSB
A3
TGC REFERENCE
TGC CONTROL
ADC
TGC AMPLIFIER Q6
500 kHz
A9
KEY
KEYING RELAY
1kHz
A2
R F CRYSTAL OSCILLATOR ASSEMBLY Q1, Q2, Q3
3MHz
A2
LOCKED OSCILLATOR Q4, Q8
100 kHz
A1
FREQUENCY DIVIDER
1kHz
10kHz
A4
KILOHERTZ FREQUENCY STABILIZER
500 kHz
RECEIVE
IF AMPL A302, A303
RF AMPL V4, V5 LF MIXER V8
A9
AGC DETECTOR CR1
A9
AGC DETECTOR CR2, CR3
A3
PRODUCT DETECTOR CR5
A3
IF AMPLIFIERS Q4, Q5
AGC
A3
IF AMPLIFIER Q3
A3
MECHANICAL FILTERS 3kHz FL1, FL2
USB
LSB
AGC
A3
IF AMPLIFIER Q2
A9
PHONE
AUDIO AMPLIFIER Q2
A9
AUDIO AMPLIFIERS Q8, Q1
SSB
AM
A12
AGC DETECTOR CR6
A9
SELCAL OUTPUT
AUDIO AMPLIFIER Q8
A9
AM DETECTOR CR4
A9
IF AMPLIFIERS Q5, Q6
A9
IF AMPLIFIER Q4
A9
MECHANICAL FILTER 6KHz FL1
A9
IF AMPLIFIER Q3
A9
AGC AMPLIFIER Q7
A9
AGC DETECTOR CR5, CR6

AT. 294

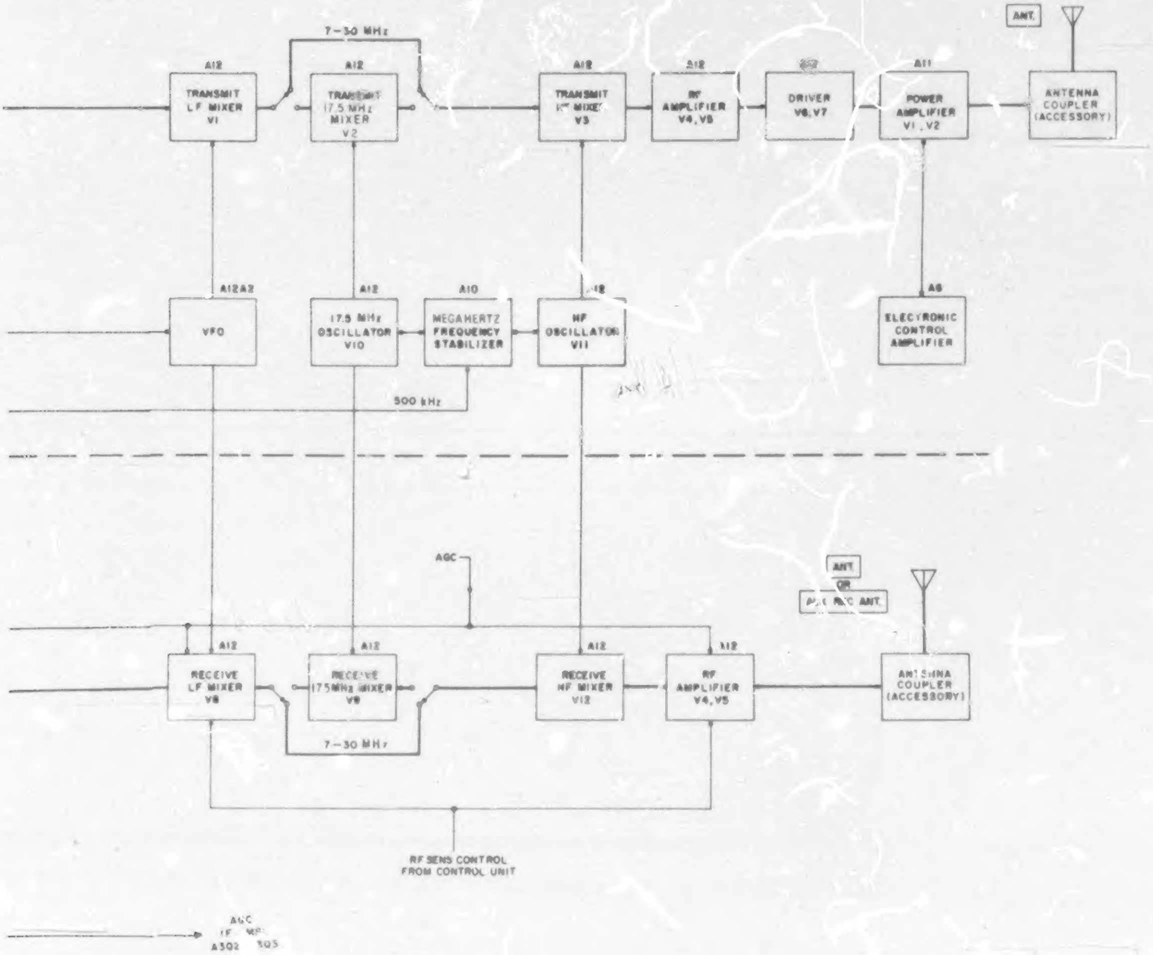
Figure 9-2.—AN/ARC-94, simplified block diagram.

The RT unit functions as a part of an overall HF communications system. Frequency selection is in increments of 1 kHz over the entire band, providing a choice of 28,000 operating frequencies.

The control unit provides for remote selection of operating frequency, and for selection of upper sideband, lower sideband, amplitude modulation, data link, or CW mode of operation.

The mounting provides for mechanical support and isolation from airframe vibration and shocks.

Operation of the set, as discussed briefly in the following paragraphs, is divided into a transmit function, a receive function, and a carrier generator function which is common to both reception and transmission. The brief discussion is in block diagram form. (Refer to fig. 9-2 in connection with the discussion.) Principal intelligence signal flow is indicated by heavy lines.


7–30 MHz
A12
TRANSMIT LF MIXER V1
A12
TRANSMIT 17.5 MHz MIXER V2
A12
TRANSMIT HF MIXER V3
A12
RF AMPLIFIER V4, V5
DRIVER V6, V7
A11
POWER AMPLIFIER V1, V2
ANT.
ANTENNA COUPLER (ACCESSORY)
A12A2
VFO
A12
17.5 MHz OSCILLATOR V10
A10
MEGAHERTZ FREQUENCY STABILIZER
A12
HF OSCILLATOR V11
A6
ELECTRONIC CONTROL AMPLIFIER
500 kHz
AGC
ANT
OR
AUX REC ANT.
A12
RECEIVE LF MIXER V8
A12
RECEIVE 17.5MHz MIXER V9
A12
RECEIVE HF MIXER V12
A12
RF AMPLIFIER V4, V5
ANTENNA COUPLER (ACCESSORY)
7–30 MHz
RF SENS CONTROL FROM CONTROL UNIT
AGC
IF AMP
A302 305

AT.294

Figure 9-2.–AN/ARC-94, simplified block diagram–Continued.

The diagram is divided functionally rather than by the physical location of the parts. Blocks and individual component parts mentioned in the discussion are referenced in the standard manner for modular construction. Modules are referenced as A1, A2, etc. Where detail parts are considered in a discussion, the module designation and the part designation are combined into a compound reference, such as A1R2, A2R2, etc., to indicate the module and specific part. Parts located on submodules are designated by a triple compound designation such as A12A2C3, where A12 is the module, A2 is the submodule, and C3 is the detail part of interest.

Transmit Function

The transmit function includes an AF input section, an IF translator section, an RF translator section, and a power amplifier section.

The AF input section provides coupling and amplification for the voice intelligence to be transmitted. The IF translator section contains the circuitry for selecting the desired mode of operation and the stages that modulate and process the desired signal accordingly. The RF translator section performs the final conversion step in translating the modulated signal information to the frequency band selected for transmission. The carrier generator function provides all the frequencies required for the double conversion transmit function. The carrier generator function also provides all the frequencies required for demodulating in the receive function. Tuning is carried out within the carrier generator function by means of an autopositioner system similar to that of the AN/ARC-88.

AF INPUT SECTION.—An audio signal from the operator's microphone, fed into the 100-ohm, unbalanced input, is amplified in audio amplifier stages A9Q1 and A9Q2 and applied to the balanced modulator in the IF translator section.

When a 600-ohm balanced audio input is used, the signal is preamplified by audio amplifier A9Q8 before being applied to A9Q1 and A9Q2.

When the transmitter is operating in the CW mode, a 1 kHz audio signal is obtained from frequency divider module A1. This 1 kHz signal is then fed from CW keying relay A9K1 to the audio input.

IF TRANSLATOR SECTION.—The audio signal from the AF input section and a carrier signal from locked oscillators A2Q4 and A2Q8 in the carrier generator function are combined in the balanced modulator. The balanced modulator yields a suppressed carrier amplitude modulated output consisting of upper and lower sidebands. The balanced modulator output is fed to automatic load control A3Q1, which is controlled by a signal fed back from the power amplifier in the power amplifier section. The output level of the automatic load control stage is adjusted by the feedback voltage to maintain the transmitter output at a predetermined level. From A3Q1, the signal is applied to A3Q2 through relay A3K5. The desired signal is then amplified by IF amplifier A3Q2 and applied to the mode selector.

The mode selector provides the option of operating in either SSB, AM, data, or CW mode. In SSB mode, the further option of using upper sideband (USB) or lower sideband (LSB) is provided.

In AM mode, the double-sideband suppressed carrier signal is applied to 3 kHz mechanical filter A3FL1, which passes only the upper sideband. A 500 kHz carrier signal from the carrier generator function is reinserted into the upper sideband at the output of filter A3FL1.

In SSB mode, the carrier reinsertion capability is disabled. The double-sideband suppressed carrier output of A3Q2 is switched to a 3 kHz mechanical filter, either A3FL1 or A3FL2, depending on the setting of the mode selector. Filter A3FL1 passes only the USB and A3FL2 passes only the LSB. The sideband not passed is suppressed. An intelligence consisting of a USB or LSB signal is then fed through relay A3K5 to IF amplifier A3Q4.

The data and CW modes are similar in function to the SSB modes since USB is always used for data and CW operation.

The desired signal is amplified in A3Q4 and fed to transmit LF mixer A12V1. Transmitter gain control amplifier A3Q6 controls the output transmission level by adjusting the gain of A3Q4 in accordance with control voltages provided in the form of a transmitter gain control signal and an automatic drive control signal.

RF TRANSLATOR SECTION.–The desired signal is mixed in A12V1 with a preselected output from the variable frequency oscillator in the carrier generator function. The output circuit of A12V1 is tuned to the difference frequency of the two signal inputs to the mixer. The frequency range of the output signal from the transmit LF mixer is 2.001 MHz to 3.00 MHz in 1 kHz increments. If the selected output frequency is to be in the range of 2.0 MHz to 6.999 MHz, the LF mixer output signal is coupled to transmit 17.5 MHz mixer A12V2. A signal is also applied to A12V2 from 17.5 MHz oscillator A12V10. The output circuit of A12V2 is tuned to the difference frequency of the two signals to produce an output frequency in the range of 14.5 MHz to 15.5 MHz. If the selected output frequency is to be in the 7.0 MHz to 30.0 MHz range, the output of A12V1 is coupled directly to A12V3. A signal is also applied to A12V3 from HF oscillator A12V11. The difference frequency of the two input signals mixed in A12V3 is at the desired output frequency and is amplified by RF amplifiers A12V4 and A12V5 and fed to drivers A12V6 and A12V7. The driver output is fed to power amplifiers A11V1 and A11V2.

POWER AMPLIFIER SECTION.–The power amplifier is band-switched by the autopositioner and tuned by a servo-driven inductance in electronic control amplifier module A6. The output of the power amplifier is designed for a 52-ohm unbalanced load and is applied to the transmitting antenna through an antenna coupler.

Receive Function

The receive function includes an RF input section, a first and second conversion section, an SSB channel, an AM channel, and an audio section.

The RF input section receives the desired signal broadcast by the remote station. The signal is amplified and sent to the first and second conversion sections, where a double conversion is performed to bring the signal to the desired intermediate frequency. In SSB, data, and CW modes, the AM channel is disabled and the desired signal is brought to the SSB channel. After being amplified to a suitable level, the desired SSB signal is demodulated in a product detector. The resultant audio signal is amplified in the audio section and applied to headset phones.

In AM mode, the SSB channel is disabled and the desired signal is brought to the AM channel. In the AM channel, a standard AM detector is used to demodulate the signal. All other functions are similar to those which occur in the SSB channel.

COMMON STAGES.–The receive function of the AN/ARC-94 uses many stages in common with the transmit function. Function selection is controlled by the operator with a push-to-talk switch. When the switch is operated, the transmit function is actuated. At all other times the receive function is actuated. A relay operated switching system shifts the assignments of the common stages between transmit and receive functions as required.

RF INPUT SECTION.–The RF input section receives the desired signal from a remote station. The impedance of the antenna is matched to that of amplifiers A12V4 and A12V5 by a suitable coupler device to insure maximum energy transfer. The amplifiers step up the received signal and apply it to receive HF mixer A12V12 in the first conversion group. RF gain is manually adjustable from the C-3940/ARC-94. The RF amplifiers are also under AGC system control.

CONVERTER SECTION.–The output of A12V4 and A12V5 is fed to receive HF mixer A12V12 where it is mixed with the signal from HF oscillator A12V11 in the carrier generator section. The output of A12V12 is coupled to receive 17.5 MHz mixer A12V9 if the operating frequency is in the range of 2.0 MHz to 6.999 MHz. It is coupled to receive LF mixer A12V8 if the operating frequency is in the range of 7.0 MHz to 30.0 MHz. The output from A12V8 is a 500 kHz IF signal. The 500 kHz IF signal is fed to either the SSB or AM channel.

SSB AND AM CHANNELS.—In SSB mode, the 500 kHz IF signal is applied to one of two mechanical filters, A3FL1 or A3FL2. Each mechanical filter has a bandwidth of 2.7 kHz. One filter passes the upper sideband, and the other passes the lower sideband. The appropriate filter is selected at the mode selector on the C-3940/ARC-94. The filter output is amplified in IF amplifiers A3Q3, A3Q4, and A3Q5. The output of A3Q5 is applied to product detector A3CR5 which recovers the audio signal.

In AM mode, the output of A12V8 is fed to IF amplifier A9Q3 for amplification and is coupled to 6 kHz mechanical filter A9FL1. The signal is then fed to three more IF amplifiers, A9Q4, A9Q5, and A9Q6. The output of A9Q6 is fed to diode detector A9CR4 which recovers the audio signal and applies it to the audio section.

AUDIO SECTION.—In either channel, the desired audio signal is amplified in audio amplifiers A9Q1, A9Q8, and A9Q2, and fed to the operator's headset. Selcal (selective calling) signals detected in AM detector A1CR4 are fed to audio amplifier A9Q9 and are coupled to the rear connector of the RT-648/ARC-94. Selcal signals are detected in all modes of operation.

Carrier Generator Function

The carrier generator function includes RF oscillator A2, frequency divider A1, kilohertz-frequency stabilizer A4, variable frequency oscillator (VFO) A12A2, 17.5 MHz oscillator A12V10, megahertz-frequency stabilizer A10, and HF oscillator A12V11.

FREQUENCY GENERATION AND STABILIZATION.—The AN/ARC-94 transmits and receives on every 1 kHz increment from 2.000 MHz to 29.999 MHz. This provides 28,000 possible separate operating frequencies. The operating frequency is selected at the C-3940/ARC-94. the 100 kHz, 10 kHz, and 1 kHz frequency selector knobs on the C-3940/ARC-94 actuate autopositioner A12A1. The autopositioner mechanically tunes variable frequency oscillator A12A2 over the range from 2.501 MHz to 3.500 MHz in 1 kHz increments. The megahertz frequency selector knob on the C-3940/ARC-94 controls a motor in RF translator module A12. This motor switches tuning elements which tune HF oscillator A12V11 to one of 28 different frequencies. The HF oscillator, in conjunction with 17.5 MHz oscillator A12V10, provides 28 1 MHz bands for each of the 1 kHz increments from variable frequency oscillator A12A2.

Megahertz-frequency stabilizer module A10 stabilizes the frequency of A12V10 and A12V11 by comparing each oscillator frequency with the frequency of a spectrum point derived from the 500 kHz output of RF oscillator module A2. The coarse frequency of A12V11 is controlled by the motor in RF translator module A12. The frequency range of A12V11 is 8.5 MHz to 32.0 MHz. The output of A12V11 is tuned to the second harmonic of the fundamental oscillator frequency when the selected operating frequency of the RT-648/ARC-94 is in the range of 14.0 MHz to 29.999 MHz. This signal is coupled to transmit HF mixer A12V3, and to receive HF mixer A12V12.

The extremely high stability of the AN/ARC-94 operating frequency is obtained by basing frequency control of the entire RT-648/ARC-94 on the frequency of a very stable crystal oscillator located in RF oscillator module A2. Frequency stability of this crystal oscillator is assured by utilizing a temperature-compensating network.

The HF and 17.5 MHz oscillators are frequency locked, and the variable frequency oscillator is phase locked to the crystal generated reference frequency by circuits in the megahertz- and kilohertz-frequency stabilizer modules. The IF injection frequency is derived from the crystal oscillator. The RT-648/ARC-94 operating frequency is thus held accurate within ±0.8 part per million per month from −40°C (−40°F) to +75°C (+167°F).

Keying Circuits

When the RT-648/ARC-94 is keyed, the keying circuits actuate the stages that must operate if the RT-648/ARC-94 is to transmit, while disabling receiver circuits that would interfere with transmission. When the key is released the keying circuits operate to switch off the transmitter and switch common stages from the transmit to the receive function.

Sidetone Circuits

The sidetone signal is taken from audio amplifier stage A9Q2 to provide audio monitoring in the transmit mode. The audio signal from the audio amplifier is fed through a keying relay and a sidetone relay (not shown) to the audio output. A combination of two voltages is used to energize the sidetone relay.

One voltage is derived from the RF output of power amplifier module A11. This RF output is rectified, filtered, and applied to the sidetone relay coil.

The second voltage, from 3-phase high-voltage power supply module A7 (not shown) is proportional to the power amplifier plate current. This voltage is the same one used for transmitter gain control in IF translator module A3. To energize the sidetone relay, sufficient plate current and plate voltage swing must be present in the power amplifier. A capacitor is placed across the coil of the sidetone relay to keep the relay energized in the sideband transmit mode when the plate current varies with the applied audio signal.

Recycle Circuits

The recycle circuits are activated when any of the frequency selector knobs on the C-3940/ARC-94 are turned. When any autopositioner operates, the recycle relay (not shown) is energized, and remains energized so long as any tuning motor is operating. The recycle relay has the following functions:

1. Disconnects transistor supply voltage to the audio amplifier in order to mute the audio during the tuning cycle.
2. Provides a ground to activate the antenna tuner.
3. Interrupts the operation of kilohertz-frequency stabilizer module A4 during the tuning cycle.
4. Disconnects the keying circuit so that the transmitter cannot be keyed during the tuning cycle.

UHF TRANSCEIVER (FM) AN/ARC-88

The purpose of Radio Set AN/ARC-88 is to provide a UHF frequency-modulated radio link between aircraft, shore, and ship. Radio Receiver-Transmitter RT-649/ARC-88 is a partially transistorized equipment capable of transmitting and receiving on any one of 1,750 frequency channels, spaced at 100 kHz intervals in the 225.0 MHz to 399.9 MHz range. The equipment receives and transmits multiplexed data information originating in the form of digital pulses from an associated equipment of a digital data communication system.

Radio Set AN/ARC-88 is supplied digital information from the associated data equipment and transmits it on a frequency modulated carrier signal. It also receives a similar frequency-modulated signal, demodulates the signal, and supples the resulting pulses to the associated data equipment. Reception and transmission are on the same frequency and utilize the same antenna.

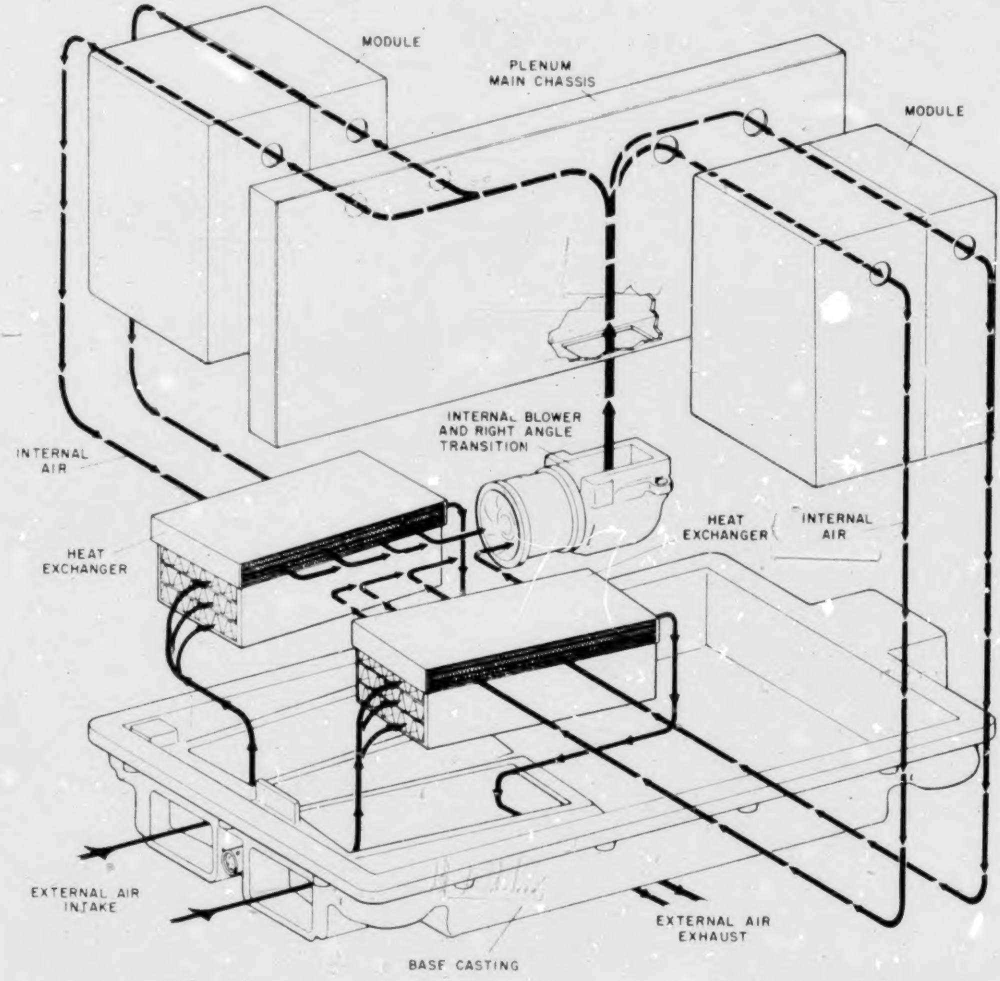
Radio Set Control C-2736A/AR provides remote selection of the 1,750 frequency channels or 19 preset channels within the specified range. (The frequencies of the 19 preset channels are determined by adjustment of a memory drum on the front panel.)

Major Components

Radio Set AN/ARC-88 consists of Radio Receiver-Transmitter RT-649/ARC-88, Mounting MT-2653/ARC, Standing Wave Ratio Indicator IM-178/ARC-88, Electronic Equipment Air Cooler HD-513/ARC, and Radio Set Control C-2736A/AR. The following paragraphs provide a brief description of these components, followed by a brief discussion of the general principles of operation of the equipment.

RECEIVER-TRANSMITTER.—Radio Receiver-Transmitter RT-649/ARC-88 consists of a main chassis, dust cover, and nine plug-in modules. The nine plug-in modules are mounted on the main chassis and enclosed in an aluminum case. An airtight seal is provided between the cover and the main chassis to permit the modules of the component to be pressurized. External cooling air is forced by the external blower through the base casting to the heat exchanger and expelled at the bottom of the unit. (See fig. 9-3.) Internal air is circulated through the internal cores of the heat exchangers, through the plenum chamber formed by the main chassis, and through each module by an internal blower. In this manner, the heat from the component is dissipated.

An antenna, two power connectors, and a pressurizing valve are mounted on the front panel. A toolkit containing special tools for maintenance is supplied with Radio Receiver-Transmitter RT-649/ARC-88.


MODULE
PLENUM MAIN CHASSIS
MODULE
INTERNAL BLOWER AND RIGHT ANGLE TRANSITION
INTERNAL AIR
HEAT EXCHANGER
HEAT EXCHANGER
INTERNAL AIR
EXTERNAL AIR INTAKE
EXTERNAL AIR EXHAUST
BASE CASTING

AT. 295

Figure 9-3.—Cooling airflow diagram.

MOUNTING.—Mounting MT-2653/ARC provides a mounting base for Radio Receiver-Transmitter RT-649/ARC-88. Vibration isolators which are usually a part of the mounting are an integral part of the mounting base casting of the RT-649/ARC-88.

SWR INDICATOR.—Standing Wave Ratio Indicator IM-178/ARC-88 provides the operator with a remote indication of transmitter power output. It is secured to the front panel of the RT unit by three cross-recessed screws. When the set is in transmit operation, the remote meter indicates incident power. By changing the connection of the remote cycle indicator to the other wire on the multiwire cable, a reflected power measurement may be obtained.

AIR COOLER.—Electronic Equipment Air Cooler HD-513/ARC is made up of a casting, single-phase blower motor, and an air inlet filter assembly. It is secured to the rear of the RT unit by four hex-socket screws. The HD-513/ARC operates when the internal temperature of the RT unit exceeds 35°C (95°F).

CONTROL UNIT.—Radio Set Control C-2736/AR is used to control Radio Receiver-Transmitter RT-649/ARC-88. A selector switch on the front panel makes 19 preset channels available to the operator. This selector switch has complete control of selection unless it is set to the M position. In the M position, adjustment of the four MANUAL frequency controls operates switches which activate an autopositioner, located in the RT unit, to set up operation at the selected frequency. A three-position rotary power switch on the front panel controls the power on-off and the selection of the associated radio equipment. Frequency adjustments for preselected channels are made by lowering a small panel at the bottom of the front panel.

Principles of Operation

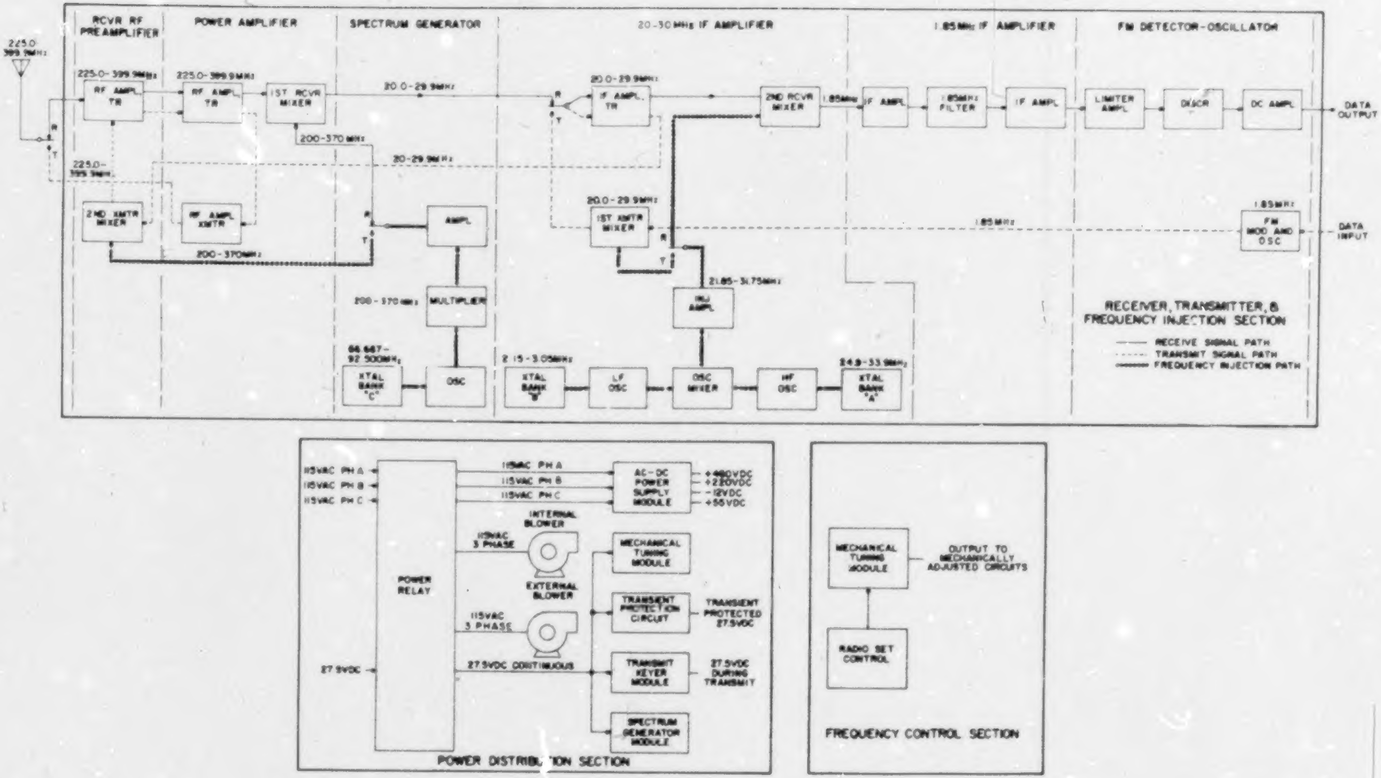
Radio Receiver-Transmitter RT-649/ARC-88 is a remotely controlled receiver and transmitter which makes use of the double-conversion superheterodyne principle. Two sources of injection frequencies are heterodyned with the signal input during receiving operation, or heterodyned with a developed carrier during transmitting operation, to produce the desired intermediate frequencies. (See fig. 9-4.)

The higher injection frequencies are developed in the spectrum generator module and are in the 200 MHz to 370 MHz range. The fundamental signals are produced by a crystal oscillator, fed through a frequency multiplier, amplified, and then applied to the first receiver mixer or the second transmitter mixer stage.

The lower injection frequencies in the 21.85 MHz to 31.75 MHz range are produced in the oscillator stages of the 20-30 MHz IF amplifier module by mixing the output of two crystal oscillators. One of these oscillators provides an output in the range of 24.9 MHz to 33.9 MHz and the other 2.15 MHz to 3.05 MHz. The heterodyne difference frequency in the 21.85 MHz to 31.75 MHz range is amplified and applied to the second receiver mixer or to the first transmitter mixer stages. Relays accomplish circuit switchover from receiver to transmit operation.

The crystal-controlled frequency generation and injection systems are ganged mechanically to the tuning mechanism of the RT unit. All tuning or channeling is accomplished by the mechanical tuning module, in response to Radio Set Control C-2736A/AR.

The received signal, consisting of a frequency shift keyed carrier within the range of 225.0 MHz to 399.9 MHz, is fed from the antenna through an antenna relay into the amplifier circuits of the receiver RF preamplifier module, and applied to an RF amplifier circuit of the power amplifier module. In the power amplifier module, the received signal is further amplified and mixed with the 200 MHz to 370 MHz injection voltage output of the spectrum generator module. The resultant 20.0 MHz to 29.9 MHz first intermediate frequency is applied to the 20-30 MHz IF amplifier module where it is mixed with the 21.85 MHz to 31.75 MHz output from the two crystal oscillators within the 20-30 MHz IF amplifier module. The heterodyned difference between the first intermediate frequency and the output from the 20-30 MHz IF amplifier module crystal oscillators is mixed in the 20-30 MHz IF amplifier module to produce the 1.85 MHz second intermediate frequency. This output is fed through a 1.85


225.0-
399.9MHz
RCVR RF PREAMPLIFIER
POWER AMPLIFIER
SPECTRUM GENERATOR
20-30 MHz IF AMPLIFIER
1.85 MHz IF AMPLIFIER
FM DETECTOR-OSCILLATOR
225.0-399.9MHz
RF AMPL TR
225.0-399.9MHz
RF AMPL TR
1ST RCVR MIXER
20.0-29.9MHz
R
T
20.0-29.9MHz
IF AMPL TR
2ND RCVR MIXER
1.85MHz
IF AMPL
1.85MHz FILTER
IF AMPL
LIMITER AMPL
DISCR
DC AMPL
DATA OUTPUT
200-370 MHz
20-29.9MHz
225.0-
399.9MHz
2ND XMTR MIXER
RF AMPL XMTR
AMPL
200-370MHz
20.0-29.9MHz
1ST XMTR MIXER
1.85MHz
1.85MHz
FM MOD AND OSC
DATA INPUT
21.85-31.75MHz
INJ AMPL
200-370MHz
MULTIPLIER
66.667-
92.500MHz
XTAL BANK "C"
OSC
2.15-3.05MHz
XTAL BANK "B"
LF OSC
OSC MIXER
HF OSC
24.9-33.9MHz
XTAL BANK "A"
RECEIVER, TRANSMITTER, & FREQUENCY INJECTION SECTION
RECEIVE SIGNAL PATH
TRANSMIT SIGNAL PATH
FREQUENCY INJECTION PATH
115VAC PH A
115VAC PH B
115VAC PH C
27.5VDC
POWER RELAY
115VAC PH A
115VAC PH B
115VAC PH C
AC-DC POWER SUPPLY MODULE
+480VDC
+220VDC
-12VDC
+55VDC
INTERNAL BLOWER
115VAC 3 PHASE
MECHANICAL TUNING MODULE
EXTERNAL BLOWER
115VAC 3 PHASE
TRANSIENT PROTECTION CIRCUIT
TRANSIENT PROTECTED 27.5VDC
27.5VDC CONTINUOUS
TRANSMIT KEYER MODULE
27.5VDC DURING TRANSMIT
SPECTRUM GENERATOR MODULE
POWER DISTRIBUTION SECTION
MECHANICAL TUNING MODULE
OUTPUT TO MECHANICALLY ADJUSTED CIRCUITS
RADIO SET CONTROL
FREQUENCY CONTROL SECTION

AT. 296

Figure 9-4.—AN/ARC-88, simplified block diagram.

MHz filter, four stages of IF amplification, and two limiter stages to a discriminator. After demodulation, the data signal is amplified in two d-c amplifier stages and fed to the associated data equipment.

The operation of transfer relays and electron tube switching, from receive to transmit or from transmit to receive operation, is accomplished by the transmit keyer module in response to data input signals from the associated data equipment.

During transmission, the initial excitation is obtained from a frequency modulator and oscillator in the FM detector-oscillator module which operates at a center frequency of 1.85 MHz and is frequency modulated with the data information furnished from the associated data equipment. The 1.85 MHz frequency-modulated signal is mixed with the 21.85 MHz to 31.75 MHz injection signal from the two crystal oscillators within the 20-30 MHz IF amplifier module. The heterodyned difference between the 1.85 MHz signal and the oscillator injection signal produces the 20 MHz to 29.9 MHz intermediate frequency. The 20 MHz to 29.9 MHz intermediate frequency is fed through two stages of amplification in the 20-30 MHz IF amplifier module and mixed in the second transmitter mixer stage of the receiver RF preamplifier module with the 200 MHz to 370 MHz injection output from the spectrum generator module. The resultant carrier frequency of 225.0 MHz to 399.9 MHz is then fed through two stages of amplification in the receiver RF amplifier module, three stages of amplification in the power amplifier module and applied to the antenna.

Channel Selection

The set contains provisions for either automatic or manual selection of the operating frequency channel. Selections of channeling mode and operating frequency are made at the control unit. Actual tuning is accomplished by mechanical linkages in the mechanical tuning module.

Both automatic and manual channel selection are accomplished by tuning the tank circuits of the receiver RF preamplifier, power amplifier, 20-30 MHz IF amplifier, and spectrum generator modules for reception or transmission on the selected frequency.

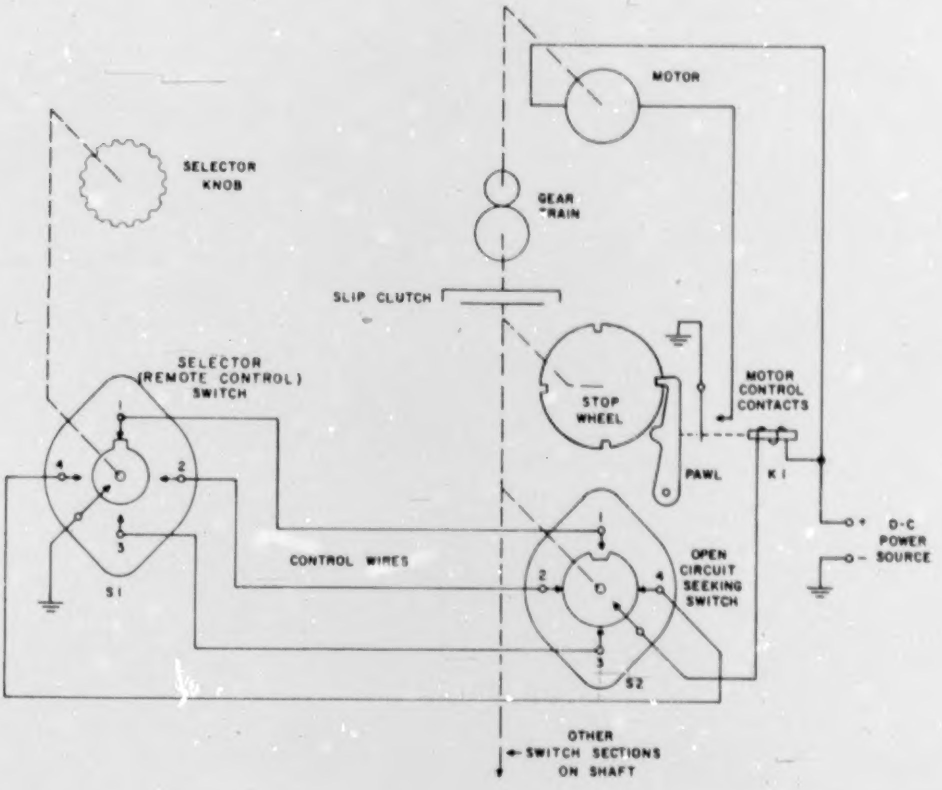
In regard to channel selection, the terms automatic and manual are used to differentiate between the selection of one of 19 preset channels by rotating the channel selector switch and the selection of one of 1,750 frequency channels by individual setting of the manual frequency controls. In either case, the actual mechanical and electrical tuning operations within the equipment are fully automatic.

Selection of any frequency is initiated when the operator rotates the decade selector to the desired frequency. By rotating a particular decade selector, the switch circuit that corresponds to the new frequency setting is grounded. By grounding the switch circuit, the positioning system of the mechanical tuning module is energized and produces a synchronized rotation of the gear train in the prescribed direction by a predetermined amount. The motion imparted to the gear train automatically adjusts the module tuned circuits for operation of the equipment on a selected frequency.

A simplified positioning system to illustrate the principle is shown in figure 9-5. The selector switch (remote control switch) chooses the operating frequency, and the seeking switch determines the angular position to which the drive motor rotates the shaft for a specific selected frequency. As shown, the equipment is at rest with the selector switch and the seeking switch at position 1. When the switches are at the corresponding position, no contact of the seeking switch is grounded through the selector switch; the electrical circuit of the drive motor is broken by the open motor control contacts of the deenergized relay.

The drive motor, which has driven the seeking switch to rest at position 1, has also driven the module tank circuits to the selected frequency in the same angular rotation.

Assume the selector switch is rotated so that the tab of the selector contacts the terminal at position 2. A closed path to ground then is completed from the +27.5-volt supply through the relay coil, the common contact and contact 2 of the seeking switch, through contact 2 of the selector switch, and to ground through the common contact of the selector switch. Relay


MOTOR
SELECTOR KNOB
GEAR TRAIN
SLIP CLUTCH
STOP WHEEL
MOTOR CONTROL CONTACTS
SELECTOR (REMOTE CONTROL) SWITCH
1
2
3
4
PAWL
K1
+
D-C POWER SOURCE
-
CONTROL WIRES
S1
1
2
3
4
OPEN CIRCUIT SEEKING SWITCH
S2
OTHER SWITCH SECTIONS ON SHAFT

AT. 297

Figure 9-5.—Automatic positioning, functional diagram.

K1 is energized and closes the motor control contacts; the drive motor then rotates in the predetermined direction. The seeking switch, which is geared to the drive motor, is driven until the cutout of the seeking switch is adjacent to position 2. At this position, the 27.5-volt path is opened, the relay releases, the motor stops, and the system comes to rest. Since the seeking switch and the tuned circuits are gear-driven by the motor, the tuned circuits are driven through the required angular displacement, which is proportional to the seeking switch travel from position 1 to position 2.

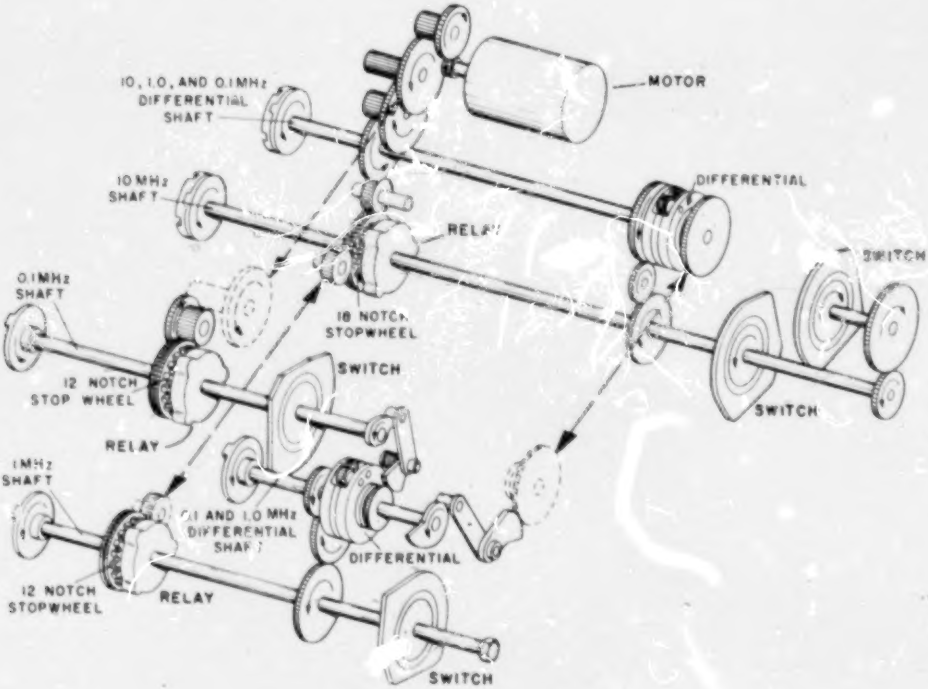
As illustrated in figure 9-5, the switch arrangement includes a notched stop wheel and pawl that accurately positions the seeking switch as soon as the drive motor is deenergized, and a clutch that decouples the switches from the drive motor and gear train when the final position is reached. Although not shown in figure 9-5, the clutch permits a single motor to drive several seeking switch shafts.

Assume the selector switch is rotated so that the circuit having the increments of the selected frequency is grounded. A complete path to ground is provided from the 27.5-volt supply through the relay coil, the seeking switch, the applicable control wire, and the selector switch. The actuated relay withdraws the pawl from the notch along the periphery of the stop wheel and energizes the drive motor through the closed motor control contacts of the relay.

The subsequent rotation of the drive motor, which is in a predetermined direction, drives the gear train, clutch, stop wheel, and seeking switch. The motor rotation is continous until the motor (and tuning gear train) has rotated through the required tuning angle; at this point, the corresponding contact of the seeking switch is open, breaking the path to ground from the 27.5-volt supply. The relay releases, permitting the pawl to engage a stop wheel notch at which time the motor control contacts open. The subsequent loss of stop wheel motion brakes the seeking switch and shaft. The kinetic energy of the drive motor (which persists after the removal of the drive motor source power) is dissipated in the gear train and clutch. At rest, the seeking switch and shaft are in a position synchronous with the position of the selector switch.

In actual practice, to insure proper positioning of the stop wheel, the seeking switch opens the relay circuit shortly before the stop wheel reaches the notch to be engaged by the pawl. The relay motor control contacts are operated mechanically by the pawl arm so the contacts remain closed until the pawl drops into the prescribed notch.

The channel selector circuits of Radio Receiver-Transmitter RT-649/ARC-88 and Radio Set Control C-2736A/AR are more complex but use the principles of the single selector-seeking system shown in figure 9-5. The actual system, however, employs three selector-seeking switch groups which are driven by a single motor. (Refer to figure 9-6.) Each of the three groups


10, 1.0, AND 0.1MHz DIFFERENTIAL SHAFT
MOTOR
10 MHz SHAFT
DIFFERENTIAL
RELAY
SWITCH
0.1MHz SHAFT
18 NOTCH STOPWHEEL
SWITCH
12 NOTCH STOP WHEEL
SWITCH
RELAY
1MHz SHAFT
0.1 AND 1.0 MHz DIFFERENTIAL SHAFT
DIFFERENTIAL
12 NOTCH STOPWHEEL
RELAY
SWITCH

AT. 298

Figure 9-6.—Mechanical turning linkages.

has individual switch connections, relay, pawl, stop wheel, and relay motor contacts.

The seeking switches are driven by the motor through three separate friction type slip clutches, one of which is attached to each of the three primary shafts. When a pawl is not engaged in a stop wheel notch, the tension in the clutch spring is sufficient to allow the motor to turn the seeking switch shaft. When the stop wheel is held by the pawl, the motor side of the clutch can rotate while the seeking switch side of the clutch remains motionless. Several seeking switch shafts thus may be independently positioned by a single drive motor and gear system.

The channel selector system is, essentially, a three-section decade system that allows two alternative methods of inserting a different frequency setting: automatic, wherein any one of 19 preset channels may be selected by the channel selector switch, and manual, wherein any one of 1,750 channels may be selected by means of four separate decade selectors, each of which must be set up individually for the frequency increment within its range. The two methods may both be subdivided into four parts consisting of the 200 MHz to 300 MHz, 10 MHz, 1.0 MHz, and 0.1 MHz decade selectors.

AUTOMATIC COMMUNICATIONS RELAY AN/ARC-52

Radio Set AN/ARC-52 provides two-way, amplitude-modulated radiotelephone communication between aircraft in flight, aircraft and shore, and aircraft and ship. It is capable of transmitting and receiving on any one of 1,750 manually selected frequency channels, spaced at 100 kHz intervals, in the band of 225.0 MHz to 399.9 MHz. It also permits the selection of any one of 18 preset channels within the specified frequency range, or the guard channel, which may be monitored on the predetermined frequency of 243.0 MHz. Auto relay is an alternate mode of operation which makes possible automatic communication relay operation.

Two receiver-transmitter units operate identically and are completely interchangeable providing correct input power is present. The only difference between the two receiver-transmitters is the input power required. Receiver-Transmitter RT-332/ARC-52 required both a-c and d-c power, while Receiver-Transmitter RT-424/ARC-52X requires only d-c power.

Unless otherwise noted, Auto Relay Control C-2791/ARC may be used interchangeably where Radio Set Control C-1607/ARC-52 is referenced, and Receiver-Transmitter RT-424/ARC-52X is used interchangeably where Receiver-Transmitter RT-332/ARC-52 is referenced.

Automatic direction finding (ADF) operation is provided by the AN/ARC-52 when used in conjunction with Direction Finder Group AN/ARA-25. During ADF operation, the AN/ARC-52 receives RF signals from a direction finding antenna and delivers appropriate signal components to the direction finder amplifying and indicating equipment.

Emergency or direction finding (DF) operation is provided by a self-generated tone that occurs between 920 and 1120 hertz. The tone modulation is a continuous signal, the interception of which may be used to locate the sending apparatus.

Automatic relay operation may be provided by two Radio Sets AN/ARC-52 connected in tandem between two prime stations. However, to provide this operation Auto Relay Control C-2791/ARC must be substituted for Radio Set Control C-1607/ARC-52 in at least one of the Radio Sets AN/ARC-52. When connected in this manner, an incoming signal received on one radio set is retransmitted automatically from the second radio set but on an alternate frequency. The range of the prime stations is thus extended since the automatic relay station effectively increases the line of sight between the two prime stations.

The intercom provision is an optional facility which can be connected for use as a backup in case the separate intercom amplifier system of the aircraft fails. When operated in this mode, the transmit function is limited to the pilot only, unless special connections are included at the time of intercom installation.

Optimum performance may be attained through the use of either a carbon or a dynamic microphone, which provides a high degree of flexibility. A change of connections within the RT unit is required when a change from a carbon type microphone to a dynamic type microphone (and vice versa) is made.

The RT unit may be installed anywhere within the aircraft through Mounting MT-1477/ARC-52. Since installation is usually external to the pressurized aircraft cabin, the RT unit case has been pressured. The pressurized case and relatively inaccessible location prohibits the replacement or repair of equipment parts while in flight. The control unit does not require a pressurized case.

RT-332/ARC-52 Unit

The RT-332/ARC-52 consists of a pressurized aluminum case, a main chassis, and 13 plug-in unit subassemblies (modules). The main chassis with mounted subassemblies, is enclosed in a double-walled, pressurized aluminum case which functions as a heat exchanger between the outside air and the air within the case. Air is forced between the walls of the case by a dual blower mounted on the front panel of the main chassis. The air is expelled through vents in the top of the case, thus dissipating the heat absorbed by the inner walls of the case. An axial-flow blower and a blower mounted on the a-c power unit circulate the air inside the case.

The modules, each of which is a functional entity, are comparatively accessible when the case is removed, so that module replacement is very easy. The mounting base for the modules is the main chassis, which provides the interunit electrical connections, plugs, jacks, and coaxial cables. The modules may be removed from the top of the main chassis by loosening the captive screws from the underside of the main chassis.

The front panel of the RT-332/ARC-52 contains the external blower and the antenna input jack. Headset and microphone jacks, test jacks, and sensitivity controls are located on the main chassis right-hand gusset plate.

RT-424/ARC-52X Unit

The RT-424/ARC-52X is identical to the RT-332/ARC-52 except it contains only 12 plug-in unit subassemblies. The a-c power unit and rectifier unit used in the RT-332/ARC-52 are removed, and a new dynamotor power supply unit is installed in its place. Circulating air is provided by the internal blower motor of the dynamotor, and by an external d-c blower motor.

Radio Set Control C-1607/ARC-52

The C-1607/ARC-52 permits remote control of the RT-332/ARC-52 operation. These controls permit the selection of operational mode, volume control, frequency channel selection (channeling), and the means to set up and record the preset frequency channels.

Auto Relay Control C-2791/ARC

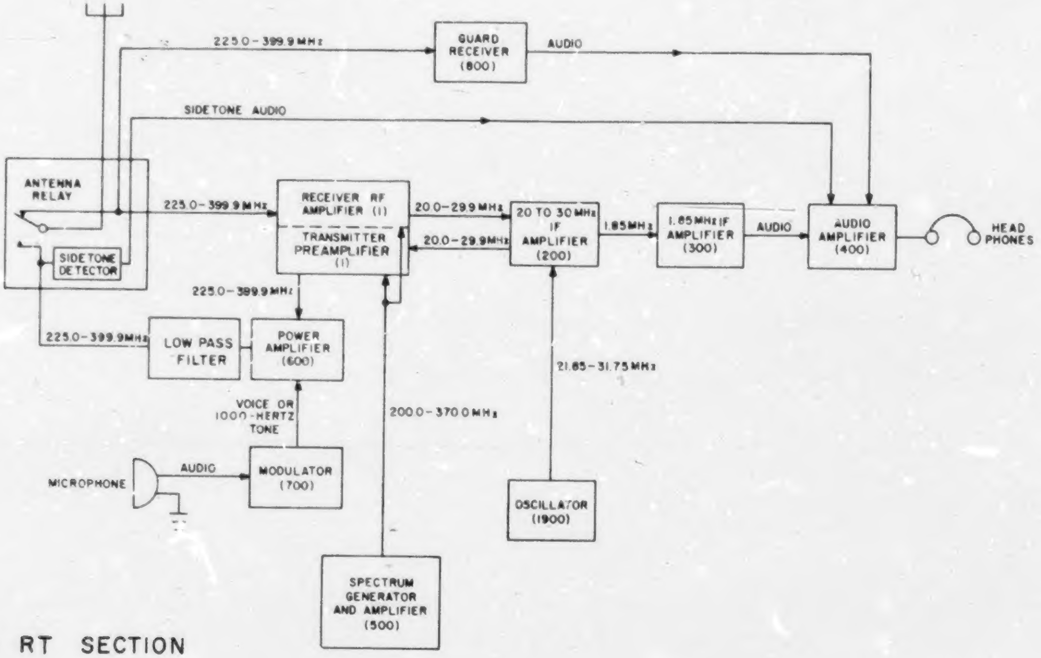
The C-2791/ARC performs all the functions of Radio Set Control C-1607/ARC-52 and additionally provides automatic relay (back-to-back) operation of two Radio Sets AN/ARC-52. The only visual difference between the radio set control and the auto relay control is the addition of an REL position to the function switch. By the addition of internal relays and the other component parts, the C-2791/ARC can place in operation two receiver-transmitters. Reception of a signal on the frequency of one receiver-transmitter will result in retransmission of the signal on the frequency of the other.

Principles of Operation

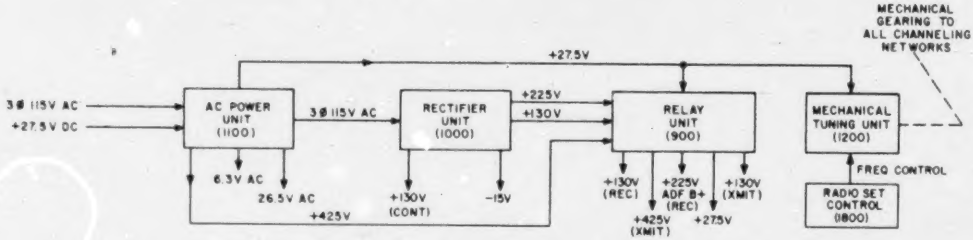
Radio Set AN/ARC-52 (fig. 9-7) is a remotely controlled transmitter and receiver unit equipped with all necessary control and mounting accessories. The transmitting and receiving components operate bilaterally; during reception the signal path is in one direction, during transmission the signal path is in the reverse direction.

The AN/ARC-52 has the greater sensitivity and the increased selectivity normally associated with double-conversion superheterodyne circuits. That is, an input signal is mixed with two separate but successive injection frequencies to obtain the desired intermediate frequency. Conversely, during transmission a basic frequency is mixed with the two injection frequencies to provide a carrier, the frequency of which is within the required range.

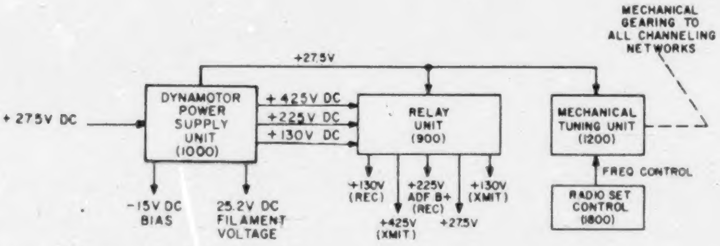
The received signal, which occurs in the 225.0 MHz to 399.9 MHz frequency range is applied to the RF amplifier and transmitter preamplifier module, where it is mixed with the 200 MHz to 370 MHz injection voltage output of the spectrum generator and amplifier module. The re-


225.0-399.9 MHz
GUARD RECEIVER (800)
AUDIO
SIDETONE AUDIO
ANTENNA RELAY
SIDETONE DETECTOR
225.0-399.9 MHz
RECEIVER RF AMPLIFIER (1)
TRANSMITTER PREAMPLIFIER (1)
20.0-29.9 MHz
20.0-29.9 MHz
20 TO 30 MHz IF AMPLIFIER (200)
1.85 MHz
1.85 MHz IF AMPLIFIER (300)
AUDIO
AUDIO AMPLIFIER (400)
HEAD PHONES
225.0-399.9 MHz
225.0-399.9 MHz
LOW PASS FILTER
POWER AMPLIFIER (600)
21.85-31.75 MHz
VOICE OR 1000-HERTZ TONE
200.0-370.0 MHz
MICROPHONE
AUDIO
MODULATOR (700)
OSCILLATOR (1900)
SPECTRUM GENERATOR AND AMPLIFIER (500)

(A) RT SECTION


MECHANICAL GEARING TO ALL CHANNELING NETWORKS
+27.5V
3Ø 115V AC
+27.5V DC
AC POWER UNIT (1100)
3Ø 115V AC
RECTIFIER UNIT (1000)
+225V
+130V
RELAY UNIT (900)
MECHANICAL TUNING UNIT (1200)
FREQ CONTROL
RADIO SET CONTROL (1800)
6.3V AC
26.5V AC
+425V
+130V (CONT)
-15V
+130V (REC)
+225V ADF B+ (REC)
+130V (XMIT)
+425V (XMIT)
+27.5V

(B) POWER SECTION, RT-332/ARC-52


MECHANICAL GEARING TO ALL CHANNELING NETWORKS
+27.5V
+27.5V DC
DYNAMOTOR POWER SUPPLY UNIT (1000)
+425V DC
+225V DC
+130V DC
RELAY UNIT (900)
MECHANICAL TUNING UNIT (1200)
FREQ CONTROL
RADIO SET CONTROL (1800)
-15V DC BIAS
25.2V DC FILAMENT VOLTAGE
+130V (REC)
+225V ADF B+ (REC)
+130V (XMIT)
+425V (XMIT)
+27.5V

(C) POWER SECTION, RT-424/ARC-52X

AT. 299

Figure 9-7.—AN/ARC-52RT unit, block diagram.

sultant 20.0 MHz to 29.9 MHz intermediate frequency is applied to the 20 MHz to 30 MHz IF amplifier module where it is mixed with the 21.85 MHz to 31.75 MHz injection voltage output of the oscillator module. The resultant 1.85 MHz intermediate frequency is filtered, amplified, and detected in the 1.85 MHz IF amplifier module and is then applied through the audio amplifier module to the headset.

The transmitter carrier is initiated within the oscillator module. The 21.85 MHz to 31.75 MHz output of the oscillator module is mixed with the 1.85 MHz signal in the 20 MHz to 30 MHz IF amplifier to produce a frequency of 20.0 MHz to 29.9 MHz. The resultant 20.0 MHz to 29.9 MHz frequency is applied to the RF amplifier and transmitter preamplifier module simultaneously with the 200 MHz to 370 MHz injection output of the spectrum generator and amplifier module. The resultant mixed carrier frequency of 225.0 MHz to 399.9 MHz is amplified and fed to the power amplifier module where it is modulated by the audio signals applied via the microphone and modulator module. The power amplifier module output, which passes through a 400 MHz low pass filter and terminates at the antenna, is a modulated carrier within the 225.0 MHz to 399.9 MHz frequency range. The modulated carrier is sampled by the sidetone detector of the antenna relay and applied to the audio amplifier module. This sidetone audio permits the operator to monitor the transmitted signal.

The guard receiver module is a single-frequency receiver which normally operates on a 243.0 MHz input frequency. The guard circuit is a double-conversion, superheterodyne type similar to the main receiver. Both receivers, however, work into a common audio output circuit.

The crystal-controlled injection systems, which are the sources of the beat frequencies, are ganged mechanically to the tuning mechanism of the AN/ARC-52 so that the selection of any frequency channels results in the development of a 20.0 MHz to 29.9 MHz and a 1.85 MHz intermediate frequency. All tuning, or channeling, is operated through the mechanical tuning unit module, the control of which is maintained at Radio Set Control C-1607/ARC-52.

The a-c power unit (RT-332/ARC-52 only, fig. 9-7 (B)) receives voltages from the 3-phase, 115-volt a-c and the 27.5-volt d-c power sources and distributes them to the required modules. The a-c voltage is applied to the rectifier unit, and the d-c voltage is applied to the relay unit and the mechanical tuning unit. In addition, the a-c power unit supplies a rectified output of 425 volts d.c. to the relay unit, and filament supplies of 6.3 volts a.c. and 26.5 volts a.c. to the appropriate filament distribution points.

The rectifier unit (RT-332/ARC-52 only) receives 115 volts a.c. from the a-c power unit and provides plate and bias voltages of +130 volts, +225 volts, and −15 volts d.c. The relay unit controls the transition between the transmit and receive function which, in turn, are controlled by the microphone press-to-talk switch. It provides three power switching functions:

1. Disable, wherein channeling will cause the AN/ARC-52 to revert to the receive function and any received audio signal is grounded.
2. Guard, wherein plate voltage is controlled for guard receiver operation.
3. Tone, wherein a continuous homing signal, 1000-Hz tone, is transmitted.

The relay unit provides selective switching of positive d-c voltages of 27.5, 130, 225, and 425 volts.

The dynamotor power supply unit (RT-424/ARC-52X only) receives 27.5 volts d.c. from an external power source and distributes this voltage to internal circuits. The same voltage also excites a dynamotor to produce d-c voltages of +425 and +130. From these voltages, additional d-c voltages of +225 (regulated) and −15 are developed. All d-c output voltages from the dynamotor power supply unit are applied, either directly or through the relay unit, to the plate, screen, and grid circuits in the receiver-transmitter.

A mechanical tuning unit controls the frequency selection of the equipment and, in turn, is remotely controlled from Radio Set Control C-1607/ARC-52. It operates in a manner similar to that on the AN/ARC-88.

TRANSCEIVER ALINEMENT AND TRACKING

A transceiver is a self-contained transmitter and receiver which share common circuits. The transmitter and receiver operate on the same frequency, and the microphone switch determines when there is an output from the transmitter. In the absence of transmission, the receiver is sensitive to incoming signals.

Some of the common circuits are the antenna, master oscillator, and RF and AF amplifiers. Advantages of these common circuits are the overall reduction of the size and weight, and the lower power demand on the aircraft system.

Since there are circuits common to both the transmitter and the receiver, alinement and tracking are unique problems of the transceiver. Alinement is the adjustment of circuits to specific frequencies, and tracking is maintaining a constant frequency relationship between two or more circuits.

In order to aline and track common circuits in a transceiver, it is necessary to refer to the Maintenance Instructions Manual for the particular equipment being used. This is because the circuits common to both the transmitter and receiver will vary from equipment to equipment; for example, between the ARC-52, ARC-88, and the ARC-94.

INTEGRATED COM-NAV-IFF SYSTEMS

The integrated communications, navigation, and identification system was brought about by the advent of the weapons system concept in naval aircraft. This system, called COM-NAV-IFF (CNI) in some installations and INTEGRATED ELECTRONIC CENTRALS (IEC) in others, is the natural result of the expanded electronic functions, restricted space, critical weight factors, and more severe environmental conditions imposed upon the newer high performance naval aircraft.

BASIC CONCEPTS

The integrated units for specific aircraft are designed to best fit into the overall weapon system of the aircraft. The system is designed to combine into one integrated system the functions previously performed by numerous independent electronic equipments. Figure 9-8 is a block diagram of a typical CNI system. Functional names of components are used rather than AN nomenclature, since this diagram is representative of a general system rather than a specific aircraft configuration.

In most CNI systems the mounting racks serve a dual purpose. They act as shock mounts and in addition serve as a specialized chamber for distributing cooling air to each of the major components. In addition, components which contain high voltage circuits are pressurized to prevent arc-over at high altitude. The units which do not require pressurization are supplied directly with cooling air.

Communications Function

UHF radio communication facilities are provided by one or more transceiver units, permitting voice transmission and reception on any of 1,750 channels in the frequency range of 225.0 MHz to 399.9 MHz. A separate fixed frequency guard channel receiver in the transceiver unit is normally tuned to the emergency frequency of 243.0 MHz. An auxiliary UHF receiver is also normally included in the system. This receiver operates on any one of 20 preset channels in the frequency range of 265.0 MHz to 284.9 MHz, and on an additional guard channel. The auxiliary receiver is employed with the UHF ADF system in order to provide independent UHF direction-finding functions without disrupting the normal communications facilities.

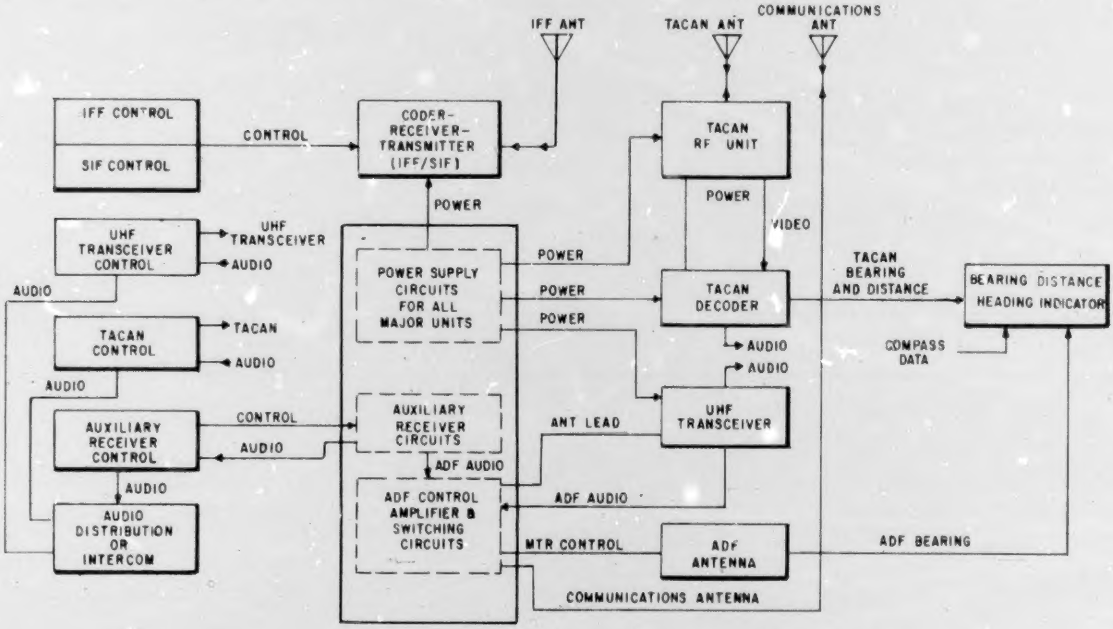
Navigation Function

The navigation function includes both TACAN and ADF. The TACAN facilities are provided by two units, a radio receiver-transmitter and a pulse decoder. The output of the pulse decoder is used to drive indicators which display bearing and distance to the selected TACAN beacon, deviation from a selected course, and TO-FROM information to indicate whether the selected course is to or from the beacon.

The UHF ADF can be operated using two receiver sources, the UHF communications receiver or the auxiliary receiver.

Identification Function

The identification facilities are provided by a pulse type transponder which automatically


IFF ANT
TACAN ANT
COMMUNICATIONS ANT
IFF CONTROL
SIF CONTROL
CONTROL
CODER-RECEIVER-TRANSMITTER (IFF/SIF)
TACAN RF UNIT
POWER
POWER
VIDEO
UHF TRANSCEIVER CONTROL
UHF TRANSCEIVER
AUDIO
AUDIO
POWER SUPPLY CIRCUITS FOR ALL MAJOR UNITS
POWER
POWER
POWER
TACAN DECODER
TACAN BEARING AND DISTANCE
BEARING DISTANCE HEADING INDICATOR
TACAN CONTROL
TACAN
AUDIO
AUDIO
AUDIO
AUDIO
COMPASS DATA
AUXILIARY RECEIVER CIRCUITS
CONTROL
AUDIO
AUXILIARY RECEIVER CONTROL
ANT LEAD
UHF TRANSCEIVER
ADF AUDIO
AUDIO
AUDIO DISTRIBUTION OR INTERCOM
ADF CONTROL AMPLIFIER & SWITCHING CIRCUITS
ADF AUDIO
MTR CONTROL
ADF ANTENNA
ADF BEARING
COMMUNICATIONS ANTENNA

AT. 290

Figure 9-8.—Typical CNI system.

radiates replies to interrogations from ground, shipboard, or airborne IFF stations. Either normal (Mark X IFF) or selective identification feature (SIF) coding of the replies may be utilized. This facility performs the functions provided by both the AN/APX-6B and the AN/APA-89 in older aircraft.

Power Supplies

Power supply modules distribute power from a centralized source to the major units. Special emergency switching features remove power from certain navigation functions to reduce the load on the power source in case of flame out, generator failure, or other emergency. The specific functions which are not available in an emergency will vary from one aircraft to another; information on this subject may be found in the technical manuals for specific aircraft models.

The centralized power supply provides a means of saving weight in an integrated installation. The components utilized in power supplies are often very heavy when compared to other electronic components; therefore, combining the power supplies eliminates numerous heavy components.

F-4B CNI SYSTEM

The CNI system for the F-4B aircraft is the Integrated Electronic Central AN/ASQ-19. It provides UHF communications, TACAN and ADF navigation, radar identification (IFF), instrumentation, and interphone functions. It is packaged in five major units: UHF Communications, unit 1; Navigational RF, unit 2; Navigational Instrumentation, unit 3; IFF/Coder, unit 4; and Auxiliary Receiver/ADF/Power Supply, unit 5. Placement of these units as well as some minor units and associated components is depicted in figure 9-9.

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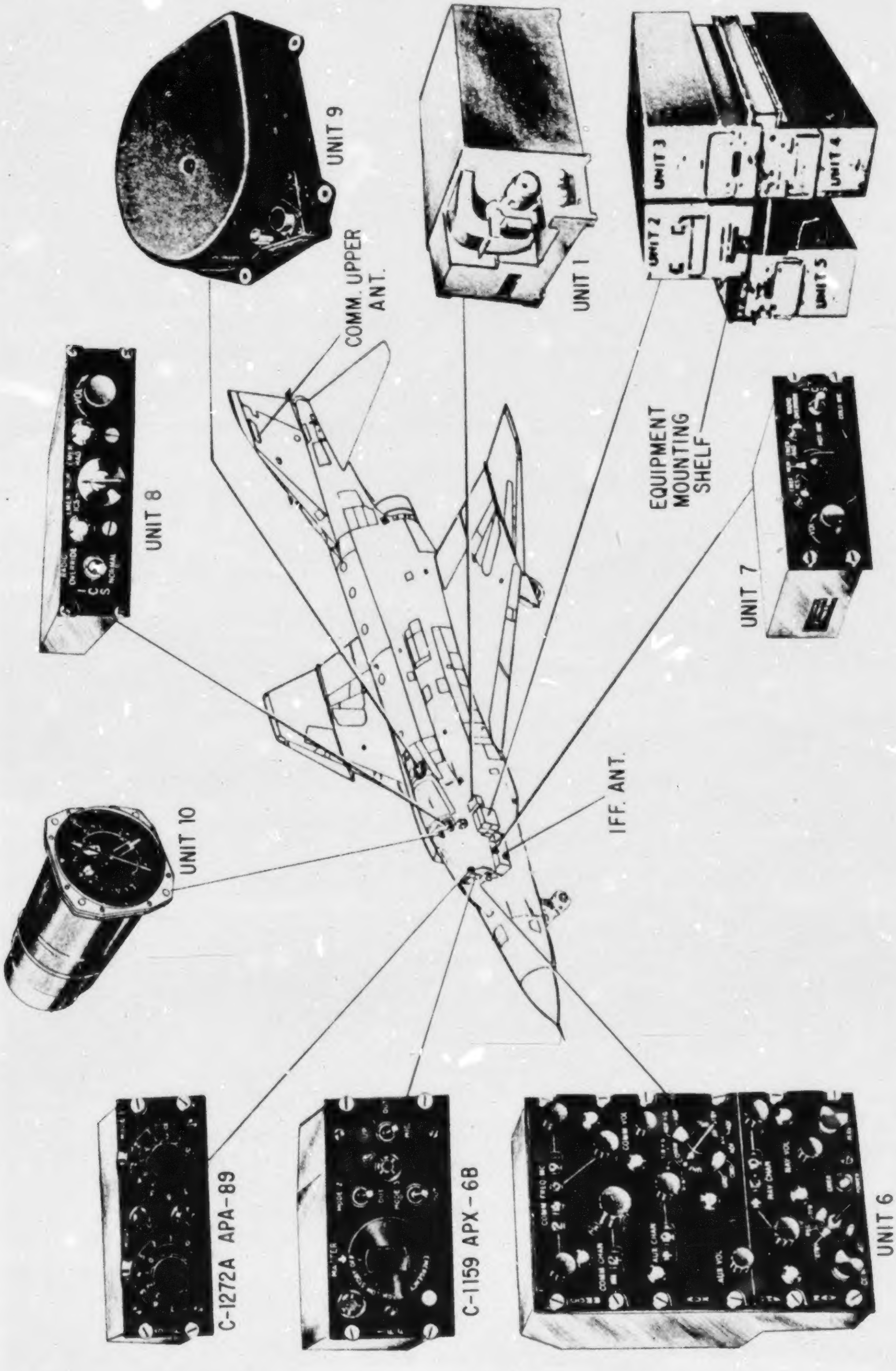

UNIT 9
COMM. UPPER ANT.
UNIT 1
UNIT 2
UNIT 3
UNIT 4
UNIT 5
EQUIPMENT MOUNTING SHELF
UNIT 8
UNIT 7
UNIT 10
IFF. ANT.
C-1272A APA-89
C-1159 APX-6B
UNIT 6

AT. 291

Figure 9-9.—Integrated Electronics Central AN/ASQ-19.

Units 2 through 5 are mounted above and below a common shelf installed aft of the aircraft's nosewheel well. The shelf as a whole is shock-mounted; it provides interunit wiring and connections, and serves as a plenum chamber for refrigerated air. Of these four units, the Navigation RF Unit is the only one in a pressurized case.

UHF Communication Unit

The UHF communication unit (fig. 9-9, unit 1), is located in the aft cockpit; it, too, is pressurized, but has a self-contained blower circulating cockpit air through a heat exchanger. Accessories to the system include fore and aft integrated control boxes, unit 6; fore and aft station intercommunication system, units 7 and 8; ADF antenna, unit 9; and bearing-distance-heading indicator, unit 10.

In general, the modules, though improved for the CNI system, were utilized in previously developed Navy modularized equipment. Radio receiver-transmitter, unit 1, is designed to provide AM radiotelephone communication in the frequency range 225.0 MHz to 399.9 MHz. It operates on any one of 1,750 frequency channels with 100 kilohertz spacing at 20 watts power output. A guard channel is provided by a separate guard receiver module incorporated as part of the circuitry of unit 1.

TACAN Units

The TACAN subsystem, units 2 and 3, uses pulsed radio signals from 962 MHz to 1213 MHz to measure aircraft distance and bearing to a TACAN surface station. There are 126 preset channels available to the operator.

Distance-measuring pulses originating in the airborne transmitter are transmitted to the ground radio station which acts as a transponder. Distance of aircraft to station is determined by measuring the elapsed time between the transmission of a challenging or interrogation pulse signal from the airborne transmitter, and the receipt of a corresponding reply pulse from the radio beacon.

Reference bursts and amplitude modulation intelligence are produced in the radio station to provide bearing and identification information for the aircraft. The radio station antenna pattern rotates at 900 rpm and produces a varying field intensity at the receiving antenna. This varying signal intensity produces the 15 Hz and 135 Hz amplitude modulation of the signal received by the airborne receiver. The reference bursts bear a constant relationship to the maximums and minimums of the rotating antenna pattern, and the consequent phase relationship of the AM and the reference bursts received by units 2 and 3 are used to determine the bearing of the aircraft with respect to the radio station.

IFF Coder Unit

The IFF-Coder, unit 4, is a pulse type transponder using a single omnidirectional receiving and transmitting antenna. The equipment normally receives on 1030 MHz and transmits on 1090 MHz. An IFF control box (Radar Set Control C-1159/APX-6B) is used to turn on the equipment and to select some of the modes of operation. The various Selective Identification Feature (SIF) reply codes for two of the three challenging signals are set up on an SIF control box (Radar Set Control C-1272A/APA-89). The third SIF code (mode 2) is set up directly on unit 4. Selection of Mark X or SIF replies is made by a switch on unit 4, and cannot be changed during flight.

The airborne antenna receives a challenging signal from interrogator equipment. This consists of pairs of pulses, with a definite time interval between the two pulses of each pair. The receiver detects and amplifies the signal and delivers it to the decoder circuits. If accepted by the decoder circuit in the equipment, the Mark X signal will go directly to the transmitter, and a reply signal is transmitted to the interrogator equipment, where the signal is then displayed on a radar indicator.

If the IFF-Coder is interrogated by an SIF challenge, the decoder output signal goes to a coding circuit in which a reply pulse train is generated. The pulse train is delivered to the transmitter. Upon being received at the interrogator, the pulse train is decoded, and the decoded signal is displayed on the radar indicator.

Auxiliary Receiver/ADF/Power Supply Unit

The system central power supply portion of unit 5 provides the B + voltages of less than 500 volts necessary for operating all units of the system. The input a-c and d-c power is supplied from two separate sets of aircraft power buses designated main and essential. When an aircraft emergency arises, power is removed from the main buses and the emergency relays are energized automatically, placing the CNI system in emergency operation. The units operating after this emergency switching takes place are the UHF Communications Unit, at reduced power, and the radar identification (IFF) equipment. The ADF and TACAN functions are inoperative since the auxiliary receiver and TACAN B + voltage is removed.

For checking the system on the ground, external power is applied to the main aircraft buses through the ground power connector. A CNI ground power switch located in the left main wheel well is provided and must be manually thrown to energize the equipment. This switch is an electrically held type that must be reset if the ground external power is interrupted. Aircraft power bypasses this switch when the engines are operating; and during flight, the system cannot be deenergized.

The remaining portions of unit 5 are the ADF and the auxiliary receiver. The ADF subsystem uses either the auxiliary receiver in unit 5 or the main receiver, unit 1, in conjunction with the ADF antenna, unit 9, to determine the bearing to a received station. The antenna element has a cardioid pattern which is switched 180° at a 100 Hz rate. The switching action produces modulation on the RF signal (which is detected in the receiver and supplied as an error signal to a servoamplifier). The servosystem positions the antenna element until it is alined with the wave front of the received signal. The antenna maintains this relationship with respect to the signal throughout normal flight maneuvers of the aircraft. The position of the antenna element, relative to the aircraft, is transmitted to the Bearing-Distance-Heading Indicator (BDHI), unit 10, and displayed on the No. 1 pointer. ADF information is also supplied to the Horizontal Situation Indicator (HSI), a part of the instrument system.

The auxiliary receiver in unit 5 is normally used for ADF, and it provides 20 preset channels over the 265.0 MHz to 284.9 MHz range, plus one guard frequency channel at a fixed 243 MHz.

Integrated Control Unit

The communication and navigation functions of the AN/ASQ-19 are controlled by the integrated control, unit 6, selected by the "take command" relays. Two take command push-button switches are located on the lower position of each unit 6. One, labeled COM CMD, determines who has control of unit 1. The other, labeled NAV CMD, determines who has control of TACAN. The frequency control for the communication system, the auxiliary receiver, and TACAN are independent of each other. The TACAN function selector also is independent. The function selector switch provides selection of the UHF communication and auxiliary receiver functions.

Intercommunication Units

The intercommunication units, units 7 and 8, of the AN/ASQ-19 provide intercockpit communication in the F-4B aircraft. Unit 7 is the intercom station in the pilot's cockpit; unit 8 is the intercom station in the radar observer's cockpit. An external intercom connection is incorporated into the system for ground personnel. The intercom stations receive and amplify signals from units 1, 2, 3, and the auxiliary receiver of unit 5. In addition, the microphone output in either cockpit is connected to the transmitter of unit 1 by operating the push-to-talk button, thus allowing either pilot or radar operator to communicate. Two transistorized, encapsulated amplifiers are used in units 7 and 8 to amplify the AF output from the microphone and the external audio inputs. Emergency switching facilities allow any one amplifier to be bypassed in the event of their failure. This permits intercockpit communication to be maintained if one amplifier goes dead in each unit.

Antenna System

The antenna system of the F-4B has a pair of antennas, upper and lower, used for both the IFF and TACAN at L band frequencies with two independent automatic antenna switches. The antennas are standard annular slot antennas. A modified blade antenna is mounted in the fin cap and used for the upper communications antenna. A low drag blade is used for the lower antenna. The pilot has the option of selecting either antenna by an antenna selector switch located on the left console of the forward cockpit. The ADF antenna, unit 9, is located on the underside, aft of the radome. This antenna works in conjunction with either the auxiliary receiver or the UHF communication system, whichever is selected for the ADF function on the integrated control box.

Construction

In the CNI system aboard the F-4B aircraft, the modular construction concept has been applied. Circuits have been broken down into functional subdivisions and packaged independently as plug-in modules adhering to a standard size factor. A major functional unit consists of a group of these modules mounted on a chassis in a case which provides interconnecting wiring, radio interference filtering, and cooling distribution.

The modular approach has given a high degree of flexibility in view of the mission and space considerations of this aircraft. It has also reduced costs and accelerated the engineering production cycle, helping to put the full weapon system into the air faster.

Cooling System

Improved thermal design is another important feature of the CNI system. Basically, the problem is to maintain the surface temperature of each component in the system at a value which will insure a high degree of component reliability. This must be done with a cooling system having the smallest possible size and weight.

Neither natural convection and radiation nor the use of integral blowers are acceptable means of cooling if high ambient temperatures (due to local heat dissipation or high aircraft skin temperatures) exist in an equipment rack. The problem is aggravated at extreme altitudes where mass flow from integral blowers drops to negligible values. A forced-air cooling system using an outside source of cooling air is required to hold the component temperatures within acceptable limits.

Since the cooling system must be held to a minimum size and weight, the CNI system is designed to minimize the power dissipation required. Careful circuit design keeps the dissipation in each module as low as practicable. The elimination of individual blowers with their inherent heat dissipation, and the use of a central power supply further reduce the overall heat produced in the system. High temperature components are used as extensively as possible to reduce the amount of cooling air required. Finally, and perhaps most important, the flow of cooling air through each module is carefully controlled to give a high degree of cooling efficiency and still prevent overcooling of any module. In this manner, the required capacity of the cooling system is kept at a minimum, and the reliability and total life of the equipment are extended to a maximum.

INTERCOMMUNICATION SYSTEMS

All aircraft intercommunication systems perform essentially the same basic functions. They deliver audio to one or more selected stations on board the aircraft to permit crewmembers to speak to each other. They also provide control of the communication facilities so that various members of the crew may receive incoming radio messages or initiate messages with the aircraft transmitters. It is also often necessary that the intercommunication system contain facilities for operating recording equipment so that permanent records may be made of the various receptions and transmissions occurring during flight.

It is not possible in the limits of the present discussion to describe all types of intercommunication systems installed in naval aircraft. A few examples are given which show characteristics common to most installations, while at the same time presenting characteristics which represent the newer developments in this type of equipment.

INTERCOMMUNICATION SET AN/AIC-14

The AN/AIC-14 ICS is an airborne internal communication system which integrates and coordinates all the audio facilities of the communication and other electronic equipment. The overall design is based on modular construction to provide a very high degree of versatility and reliability. Easily replaceable plug-in transistorized amplifier modules insure reliability under severe environmental conditions. A variety of individual component parts and subassemblies are available for use with and within the system, permitting adaptation of the basic system for use in many different types of installations having various audio requirements. Thus the basic system and its numerous variations provide for almost trouble-free service over prolonged operating periods.

The maximum capability for AIC-14 interphone installations in a single system permits operation of any combination of up to 30 individual stations without readjustment of the interphone volume control. Under maximum usage the overall output level from the control unit does not vary by more than 3 db. All signal inputs are isolated from each other by at least 50 db, thus minimizing the effect of a single station on the operation of the overall system.

In addition to the interphone stations which are normally manned during aircraft operations, auxiliary stations may be provided for use by ground personnel during maintenance, inspection, or servicing of the aircraft. Any combination of audio inputs (up to a total of 30) may be monitored without requiring adjustment of the volume control. Through operation of control switches, up to 11 outputs may be controlled.

The selection and monitoring of interphone and radio receiver signals, as well as the selection of transmitters to be keyed, is accomplished through selector switches and controls located on the front panels of the units to be controlled. The modes of operation (normal or auxiliary) and the energizing or deenergizing of interphone station microphones are controlled by operating appropriate switches on the front panel of the interphone control. The interphone control also permits the use of external keying switches.

To illustrate the flexibility and versatility of the AN/AIC-14 system, some of the various types of components and accessories are described briefly. The discussion is limited to the important features and peculiar applications of each item discussed. The list, although quite extensive, is far from a complete listing of items used in conjunction with the AN/AIC-14 Intercommunication Set.

Control Units

Control, Interphone C-2645A/(or C-2645B)/AIC-14 is the master control unit for the system, and is located at all manned interphone stations. Two transistorized plug-in amplifier modules (one isolation and one interphone) are included in each unit. The isolation amplifier provides the amplification and isolation necessary for all incoming audio (interphone and radio receiver). The interphone amplifier provides the amplification and isolation necessary for all outgoing audio (from the station's microphone). Each amplifier is capable of delivering a nominal output power of 300 milliwatts to the stations' earphones or to the interphone line.

The control unit also provides an alternate mode of operation for either or both amplifiers. If one amplifier becomes inoperative, its functions may be shifted to the other; if both the amplifiers become inoperative, they may be bypassed by switching to the EMERG position. In the emergency mode, incoming signals are supplied directly to the headset and outgoing signals are fed directly to the transmitter; no interphone communication is possible.

In almost all aircraft, additional control units are used to extend and expand the capacity of the ICS. A few such auxiliary control units are discussed briefly in the following paragraphs.

The C-2642/ or C-2642A/AIC-14 provides a means for selecting transmitter or interphone operation, interphone disconnect, and volume adjustment of incoming radio receiver signals. Any one of up to 11 transmitters can be selected.

The C-2643/AIC-14 is a selector panel for radio receivers and transmitters, permitting selection of any combination of two transmitters and four receivers. It incorporates isolation networks for all incoming signals.

The C-2644/AIC-14 incorporates facilities for selecting transmit or receive operation, a volume control for mixed radio receiver signals, and isolation for all incoming signals.

The C-2646/AIC-14 is an auxiliary control used primarily by maintenance personnel. It is located at auxiliary stations not normally manned during flight. It uses the common audio line for both incoming and outgoing interphone signals, and permits communication with any station which is connected to the common audio line.

The control contains a single amplifier. Incoming audio signals are isolated and amplified; in this case the amplifier acts as an isolation amplifier. When a push-to-talk circuit is energized, the microphone input is amplified and fed to the common line; the amplifier then switches to interphone operation.

The microphone and headset jacks can be used only with a 600-ohm headset and a carbon microphone with a nominal impedance of 100 ohms. When a dynamic microphone and low impedance headset are used, signal preamplification and transformer matching are required. This may be conveniently accomplished with the use of associated accessory cordsets discussed later in this chapter.

The mounting plate MT-2075/AIC-14 is used in conjunction with the C-2646. It includes a quick-dismounting feature provided by four slide fasteners which are secured by lockwire.

The C-2647/ or C-2647A/AIC-14 provides facilities for increasing the number of either receivers or interphone stations. It provides isolation for all signals. The function as interphone station selector or as receiver selector is determined by the position of an internal plug-in unit. This function is established at the time of installation, and is not normally changed thereafter.

When used as a receiver selector, any one or any combination of 12 receivers may be selected and isolated. When used as an interphone station selector, the unit selects and isolates any one or any combination of 12 signals. An alternate provision enables position 12 to be used either to select a specific station or as an "all-call" for up to 11 stations.

The C-2648/ or C-2648A/AIC-14 control permits selection of six additional receivers or interphone stations. In other respects it is similar to the C-2647.

Interconnection Box J-1013/AIC

This accessory enables the AN/AIC-14 to operate with either carbon or dynamic microphones and either high or low impedance headsets. The unit contains a 60-db transistorized preamplifier and two impedance matching transformers. The preamplifier and transformers may or may not be used, depending on the position of the connecting links in the box. A table illustrating the link settings for various types of microphones and headsets is located on the inside of the cover plate.

Microphones

A carbon microphone may be connected directly into the AN/AIC-14 Intercommunication Set, or it may be connected through a J-1013 interconnection box. If the J-1013 is used, the links must be set so as to bypass the microphone preamplifier. Dynamic microphones, if used, must be connected through the J-1013. The links must be set so that the 60-db gain of the microphone preamplifier is used.

The RS-38D-2 is a hand-held, high output (0.25-volt, rms), noise-canceling carbon microphone. Its termination (plug PJ-068) mates with the MIKE jack on the interphone control C-2646 or on any installation which accommodates conventional carbon microphones.

The M-3A/A is a high output (0.25-volt, rms), boom-mounted, noise-canceling carbon microphone. Its termination (PJ-292) is a two-prong plug which mates with the receptacle on the H-173/AIC headset and the CX-1301/AR cordset.

The ANB-M-C1 is a high output (0.25-volt, rms) carbon microphone normally used in oxygen masks. It terminates in the PJ 292 plug.

The M-92/U is a hand-held, noise-canceling, dynamic microphone with a built-in transistorized amplifier. In appearance and characteristics it is the equivalent of the RS-38D-2 carbon microphone, and may be used interchangeably with it. If a J-1013 is used, the link settings should bypass the preamplifier.

The M-96/A is a boom-mounted, noise-canceling, dynamic microphone similar in appearance to the M-3A/A carbon microphone and terminated in the same type (PJ-292) plug. In use, however, the two are not interchangeable. The M-96/A has a nominal output impedance of 7 ohms, and delivers an output voltage of 300 to 500 microvolts. The J-1013 must be used, and the microphone preamplifier and the appropriate impedance matching transformer must be connected by the changeable links.

The M-94/A is the dynamic microphone used in oxygen masks. In appearance it resembles the AMB-M-C1, but the two are not operationally interchangeable. In electrical characteristics and service limitations, the M-94/A resembles the M-96/A.

Earphones and Headsets

Several types of earphones and headsets are used with the AN/AIC-14 system. In actual practice the headsets may be so constructed that the earphones are either used separately (splitphone) or connected in parallel. They may have either a low or a high impedance.

Earphones H-87B/U are the dynamic type commonly used in helmets and headsets. The earphones have an impedance of 7 ohms as compared to the 600-ohm impedance of the ICS. The phones may be connected to a cordset which is terminated in a short plug. In this arrangement, an impedance matching transformer in the plug permits the H-87B/U to be inserted directly into the ICS control box. If connected through the J-1013, the links should bypass the impedance transformers.

By using the cordset CX-4832 the earphones are connected in parallel, offering a 7-ohm impedance. This combination requires use of the J-1013 and its impedance matching transformers.

The H-173/AIC headset is a lightweight unit which is designed for maximum wearing comfort. It contains the H-87B/U earphones and incorporates provisions for mounting boom microphones. The earpieces eliminate most of the surrounding noise. A quick-disconnect feature provides safety and ease of handling.

The H-3/ARR-3 is a dynamic headset with built-in impedance matching transformer, which adapts the 7-ohm phones to the 600-ohm system. This allows the headset to be directly inserted into the ICS. If connected through a J-1013, the impedance transformer must be bypassed.

Cordsets

Many types of cordsets are used with the AN/AIC-14. These cordsets are used for connecting the various types of microphones, headsets, and connection boxes within the system. Some include amplifiers and/or impedance transformers; others do not. The following paragraphs present a brief discussion of several of these cordsets.

The CX-1301/AR is a coiled cordset terminated on one end with a Junction Box J-193/AR and on the other end with a U61-U receptacle. The cordset is normally used with carbon microphones and high impedance headsets. If incompatible accessories are used, the J-193/AR is removed from its mounting and the CX-1301/AR is replaced by a J-1013. The mounting holes of both connecting boxes coincide.

The CX-4620/AR is a 75-foot, 5-conductor cable with an in-the-line switch containing a preamplifier, impedance transformer, and microphone keying switch. One end is terminated in a connector which mates with the J-1013 input connector. The other end mates with the H-173/AIC headset or a hardhat. This cordset may be used only with a dynamic microphone and a low impedance headset. However, the adjustable links in the J-1013 must be set to accommodate a carbon microphone and high impedance headset combination.

The CX-4621/AR is a 6-foot, 5-conductor, coiled cordset with terminations identical to those of the CX-4620/AR. Since it contains no preamplifier or impedance matching transformers, it may be used with either type headset and microphone. However, the links in the J-1013 must be connected accordingly.

The CX-4623/AR is a 9-foot, 5-conductor, coiled cordset. It includes an in-the-line switch similar to that in the CX-4620/AR, and is terminated in the same type connectors. It may be used only with a dynamic microphone and low impedance headset, but the J-1013 links must be set for the carbon microphone and high impedance headset combination.

The CX-4832/AR cordset is used to connect the earpieces of the H-87B/U in parallel, thus providing a low impedance output.

INTERCOMMUNICATION SET AN/AIC-15

The AN/AIC-15 system marks a milestone in adaptation of transistor circuits to airborne applications in a form suitable for manufacture on a production basis. The total equipment consists of six types of major components: four types of station control boxes, a recorder control, and an interconnecting box.

Each of the control boxes with the exception of the recorder unit contains one microphone amplifier and one receiver amplifier. The type of box installed at a particular station of the aircraft is determined by the communication functions to be performed at that station. All boxes provide essentially the same intercom and receiver facilities. The system is not restricted to use with any specific radio receiver, recorder, or transmitter, but may be used with many different radio communication equipments.

System Operation

The major components of the AIC-15 are connected as shown in the block diagram in figure 9-10. The master unit (C-1908) contains controls for the complete set of radio and intercom facilities. The flight crew control (C-1910) provides the means for controlling two radio transmitters and for listening to two radio receivers. The recorder control (C-1912) serves to route any of the signals present to a tape recorder so that it is possible to preserve the audio information exchanged during operation.

The central unit of the system, Interconnecting Box, J-758, connects incoming receiver signals to the various stations and also connects the control boxes to the aircraft transmitters for control of the latter during transmission. The interconnecting box can also be used as an additional control station since it contains jacks for a microphone and a headset.

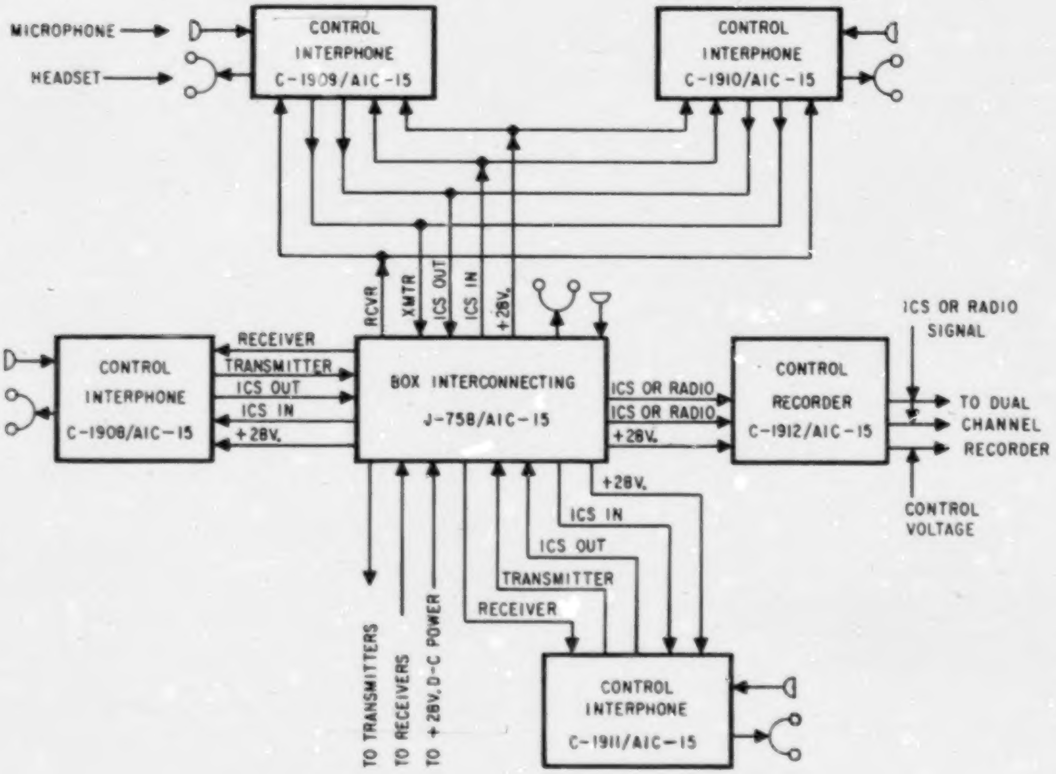
Each of the station control boxes contains a microphone amplifier and a receiver amplifier and is therefore independent of any outside aid except d-c power. Thus, external cables are not required as would be the case with external amplifiers; and smaller wires are used due to lower power requirements. As a result, approximately 60 pounds of cable weight are eliminated in comparison with electron-tube counterparts of the system. An additional advantage of this compact method of amplifier packaging is increased flexibility, in that the number of control units can be decreased or increased without causing any deterioration in the performance of the system.

Because of the relatively low power consumption of the AIC-15, the system contains no on-off switch as such. The equipment is powered from a 28-volt, d-c supply and remains in the ON condition as long as the aircraft power system is in operation.

All audio switches are semiconductor devices. By placing an appropriate d-c bias on a particular interphone line, audio on that line can be routed into the control boxes attached to it. The audio switch for each interphone line is a germanium diode which acts as a short circuit to audio when a forward d-c bias is established. Conversely, the diode acts as an open circuit when back biased, thereby disconnecting the interphone line from the associated control boxes.

Under certain conditions it is necessary to use the intercom facilities while monitoring the output of the aircraft radio receivers. It is then desirable to reduce the volume of the receiver audio without eliminating it entirely. To accomplish this, the nonlinear impedance feature of a transistor is used to reduce the receiver audio that is present with the interphone signal at the receiver amplifier.

The radio volume is lowered by means of a d-c bias applied to the volume-reduction transistor, thereby changing the latter from a nonconductive to a conducting state. This, in turn, changes the impedance of the radio receiver audio input network in such a manner as to reduce the applied audio. As a result, the volume of the output from any radio receiver selected at


MICROPHONE
HEADSET
CONTROL
INTERPHONE
C-1909/AIC-15
CONTROL
INTERPHONE
C-1910/AIC-15
RCVR
XMTR
ICS OUT
ICS IN
+28V.
CONTROL
INTERPHONE
C-1908/AIC-15
RECEIVER
TRANSMITTER
ICS OUT
ICS IN
+28V.
BOX INTERCONNECTING
J-758/AIC-15
ICS OR RADIO
ICS OR RADIO
+28V.
CONTROL
RECORDER
C-1912/AIC-15
ICS OR RADIO SIGNAL
TO DUAL CHANNEL RECORDER
CONTROL VOLTAGE
+28V.
ICS IN
ICS OUT
TRANSMITTER
RECEIVER
TO TRANSMITTERS
TO RECEIVERS
TO +28V. D-C POWER
CONTROL
INTERPHONE
C-1911/AIC-15

AT. 300

Figure 9-10.—AN/AIC-15, system block diagram.

a given control unit is reduced approximately 10 decibels with respect to the interphone level.

Interphone Circuits

A single interphone line is employed with each type of control station in the AIC-15 system. For example, the pilot, copilot, and radio operator are on a single interphone line and the remaining crew stations are on another. There is also a separate line to which all control stations are connected, which makes it possible to talk from any control box to all other stations in the system.

An emergency, or override, feature is provided by a separate line under control of the pilot, copilot, or radio operator. The emergency line can be switched on quickly and communication established with all crewmembers on the aircraft.

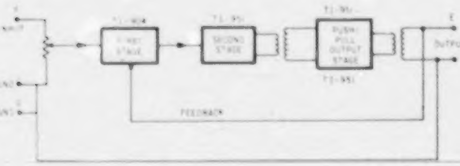
In addition to the interphone facilities, the AIC-15 circuits provide the means for listening to any combination of 9 radio receivers and for controlling the operation of any of 9 radio transmitters. The total number of stations may be as high as 13, a relatively large capability which is achieved with comparatively small requirements of space, weight, and power. The system is designed to operate on 10 watts of 28-volt, d-c power per control unit.

Transistor Amplifiers

As stated above all the station control boxes (with the exception of the recorder unit) contain two compactly packaged transistor amplifiers–one for microphone amplification and the other for receiver audio amplification. Electrically, the two amplifiers are almost identical. The input circuit of the microphone amplifier is designed to work with a carbon microphone, whereas the input of the receiver amplifier is a conventional RC coupled, 600-ohms circuit. The output circuit in both is transformer coupled, consisting of an 800-ohm output from the microphone unit and a 600-ohm output from the receiver amplifier. Both are three-stage amplifiers with push-pull output and overall negative feedback. The receiver amplifier is illustrated in block diagram form in figure 9-11.

Both the microphone and receiver amplifiers employ silicon transistors. The input stage of the receiver unit is a type 904. The 951 transistor driver is transformer coupled to two 951 transistors which serve as a push-pull output stage. The first two stages are grounded emitter circuits with collector-to-base negative feedback and emitter resistance temperature stabilization. The output stage is a grounded base circuit biased for class B operation. An overall negative feedback loop of about 20 decibels is used to further stabilize the circuit operation.

The overall dimensions of each AIC-15 amplifier are 2.44 by 1.72 by 1.00 inches. The maximum power gain is approximately 35 decibels with a gain control provided to reduce the output signal to zero. The amplifiers are capable of an output of 300 milliwatts at less than 10 percent distortion and an output of 150 milliwatts at less than 5 percent distortion. The frequency response is flat within ±2 decibels from 400 to 6,000 hertz. Satisfactory operation is maintained over the input B-plus voltage range of 22 to 30 volts d.c. About 80 milliamperes of current are required at the 28-volt B-plus level.



AT. 301

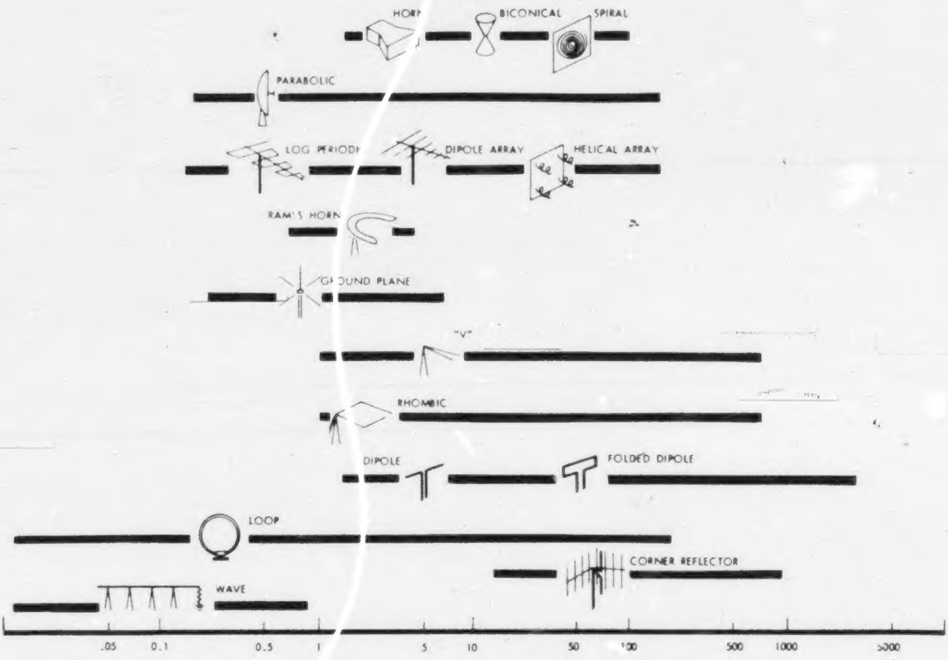
Figure 9-11.–Block diagram of the transistorized receiver amplifier.

The amplifiers are potted to reduce vibration damage. For maintenance, the entire unit is replaced and no attempt is made to repair any component within the amplifiers. The weight of each amplifier is approximately 5 ounces, a very favorable figure when compared with a weight of 13 to 15 pounds in comparable units of older systems. Also with lower power requirements, an approximate reduction in load of 20 percent is realized.

Intercommunication Set AN/AIC-15 is of considerable importance for the Aviation Electronics Technician since it is one of the first completely transistorized electronic systems which have demonstrated capability of meeting all military requirements of its class and which has definite advantages when compared with hitherto standard designs. Among these are a relatively larger number of facilities controlled, less size and weight, lower power requirements, and greater reliability and flexibility as compared to its vacuum tube counterparts. The design specifications require at least 2,000 hours of satisfactory service without removal for bench servicing, a feature of essential importance for maintenance personnel. From the standpoint of operation, one of the outstanding features of the system is its clearness of transmission.

COMMUNICATION ANTENNAS

An antenna is a special type of electrical circuit intentionally designed to radiate and/or receive electromagnetic energy. In an ordinary circuit, the inductance, capacitance, and resistance are lumped constants and therefore the electromagnetic field is confined to the circuit where it performs useful work. In an antenna, the L, C, and R properties are distributed and the electromagnetic field is not confined–it is



AT.227

Figure 9-12.—Antenna selection based on typical operating frequencies in megahertz.

spread out and tends to escape or radiate. It is this radiated field which provides the link between a transmitter and receiver.

The method of propagation is of interest, but of more concern to the technician is how the energy can be directed (the radiation pattern) and concentrated (the beamwidth), and how the efficiency (gain) can be enhanced. A familiarity with the basic types of antenna systems and the polarization of the transmitted wave provides a background of information and an appreciation of the problems involved in the selection of a suitable antenna type for a specific application.

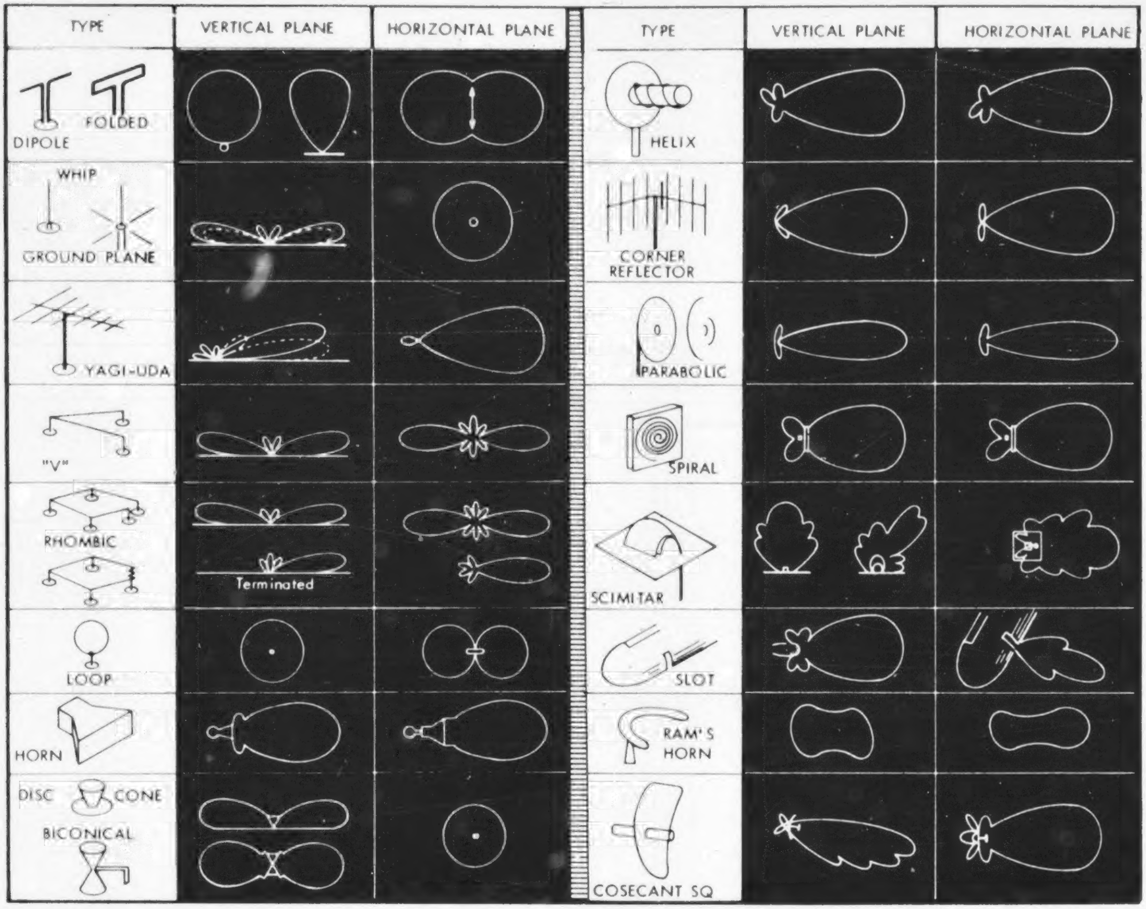
Several of the more common antenna configurations with typical operating frequency ranges and radiation patterns are shown in figures 9-12 and 9-13. These figures should be consulted throughout the discussions which follow. Table 9-1 lists the normal polarization and directional characteristics of certain antenna types.

While the simplest type of antenna is the bidirectional dipole, limitations in directivity, frequency passband, and gain somewhat restrict its use. Other dipole configurations such as the ram's horn and the corner reflector are used for special applications.

Although the crossed dipole, the whip, the top-loaded vertical, or the "J" is sometimes used, the ground plane antenna is probably the most popular when reception or transmission must be equally effective in all directions (omnidirectional). For much higher frequencies, the biconical or the disk horn is recommended.

The log periodic, helical, and flat-spiral antennas are noted for their extremely wide (as high as 20:1) operating frequency range.

When space is not a controlling factor, the rhombic and the "V" type are often used to provide high gain and directivity. Both types normally are bidirectional. The rhombic can be


TYPE
VERTICAL PLANE
HORIZONTAL PLANE
TYPE
VERTICAL PLANE
HORIZONTAL PLANE
DIPOLE
FOLDED
WHIP
GROUND PLANE
YAGI-UDA
"V"
RHOMBIC
Terminated
LOOP
HORN
DISC
CONE
BICONICAL
HELIX
CORNER REFLECTOR
PARABOLIC
SPIRAL
SCIMITAR
SLOT
RAM'S HORN
COSECANT SQ

AT. 228

Figure 9-13.—Typical radiation patterns for selected types of antennas.

made unidirectional by terminating the ends of the legs with a noninductive resistor. The "V" is made unidirectional by the use of another "V" spaced an odd number of quarter wavelengths behind the original. Typical legs for the rhombic are three to four wavelengths; for the "V" type, legs of eight wavelengths are not uncommon.

The parabolic antenna is capable of producing high gain and excellent directivity. Although screen mesh or even a grid or rods may be used where wind resistance is a design factor, the reflector element generally consists of a solid surface. Physically the reflector should be several wavelengths in diameter. Additional gain also can be obtained by mounting a hemispherical reflector in front of the dipole, provided its surface area does not appreciably shadow the rear parabolic reflector. The radiating element may be a dipole, a horn, or other suitable radiator.

Table 9-1.—Antenna characteristics.

Type	Usual polarization	Directivity
Dipole	Horizontal	Bidirectional
Dipole array	Horizontal	Unidirectional
Ground plane	Vertical	Omnidirectional
Parabolic	Horizontal	Unidirectional
Horn	Horizontal	Unidirectional
Corner reflector	Vertical	Unidirectional
Helical array	Circular	Unidirectional
Ram's horn	Horizontal	Bidirectional
Rhombic	Horizontal	Bidirectional, unidirectional
Log periodic	Horizontal	Unidirectional
Spiral	Circular	Bidirectional
Loop	Horizontal	Bidirectional
Biconical	Horizontal	Omnidirectional

CHAPTER 10

AIRBORNE NAVIGATION EQUIPMENT

Airborne navigation equipment is a term embracing many systems and instruments. The technician is required to maintain and, in some instances, to operate various equipments. This chapter includes a discussion of the major navigational systems in present use, with reference to some typical equipments. These systems include electronic altimeters, altitude warning systems, radio range and related facilities, TACAN, loran, and radio direction finders.

ELECTRONIC ALTIMETERS

Electronic altimeters (radar altimeters) may operate on frequency-modulation principles, pulse modulated principles, or a combination of both. Electronic altimeters are frequently referred to as absolute altimeters, because they are used to measure height above the terrain rather than with respect to sea level.

This chapter contains a brief discussion of two of the later and more accurate altimeters presently in use in the fleet, and a radar altitude warning system associated with one of the altimeters.

ELECTRONIC ALTIMETER AN/APN-120

The Altimeter Set, Electronic, AN/APN-120 furnishes accurate radar altitude (above terrain) indications over all types of terrain and under any weather conditions. It operates on two ranges. The low range measures altitude up to 3,000 feet; the high range measures altitude from 500 feet to the maximum altitude of the aircraft. It is installed in the RA-5C model aircraft and is an integral part of the weapons system. In addition to furnishing accurate altitude data for the pilot, the system also supplies data for correcting the barometric altitude calculated by the air data system. (See fig. 10-1.) The final corrected barometric altitude information is used by the bomb directing set to compute weapon delivery patterns.

Characteristics

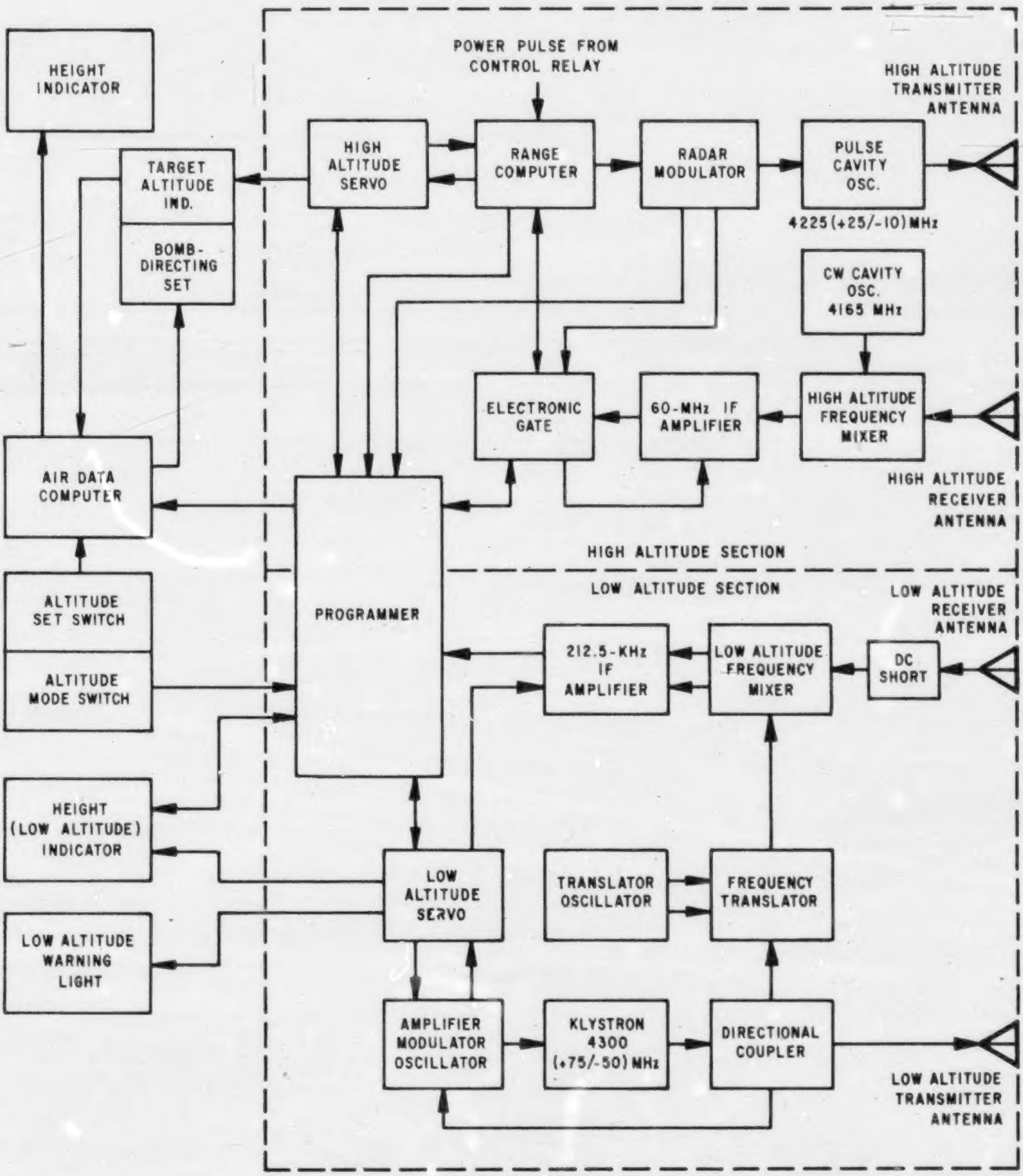
The altimeter system consists of a hybrid radar system. The low altitude subsystem consists of an amplitude-modulated, frequency-modulated, continuous-wave (AM-FM-CW) radar set; the high altitude subsystem is of the pulsed type. Provisions are made for a low altitude warning light, which actuates at 400 feet above the terrain, and an indicator of signal reliability.

Theory of Operation

For purposes of this discussion, the theory of operation for the AN/APN-120 is divided into a brief discussion of the functional loops. For detailed information regarding this equipment, refer to the applicable Maintenance Instructions Manuals. Figure 10-1 is a simplified block diagram of the altimeter, and should be referred to frequently in connection with this discussion.

System functional loops represent the complete paths of signal flow within the system, subsystems, and circuits. These loops are not limited by their packaging or "black box" location.

LOW ALTITUDE MEASUREMENT LOOP.– The low altitude system transmits and receives an RF carrier which is frequency modulated by 25 kHz, and then amplitude modulated by a 400-hertz voltage. The 25-kHz modulation is


HEIGHT INDICATOR
POWER PULSE FROM CONTROL RELAY
HIGH ALTITUDE TRANSMITTER ANTENNA
TARGET ALTITUDE IND.
HIGH ALTITUDE SERVO
RANGE COMPUTER
RADAR MODULATOR
PULSE CAVITY OSC.
4225(+25/-10)MHz
BOMB-DIRECTING SET
CW CAVITY OSC. 4165 MHz
ELECTRONIC GATE
60-MHz IF AMPLIFIER
HIGH ALTITUDE FREQUENCY MIXER
AIR DATA COMPUTER
HIGH ALTITUDE RECEIVER ANTENNA
HIGH ALTITUDE SECTION
LOW ALTITUDE SECTION
ALTITUDE SET SWITCH
PROGRAMMER
LOW ALTITUDE RECEIVER ANTENNA
ALTITUDE MODE SWITCH
212.5-KHz IF AMPLIFIER
LOW ALTITUDE FREQUENCY MIXER
DC SHORT
HEIGHT (LOW ALTITUDE) INDICATOR
LOW ALTITUDE SERVO
TRANSLATOR OSCILLATOR
FREQUENCY TRANSLATOR
LOW ALTITUDE WARNING LIGHT
AMPLIFIER MODULATOR OSCILLATOR
KLYSTRON 4300 (+75/-50) MHz
DIRECTIONAL COUPLER
LOW ALTITUDE TRANSMITTER ANTENNA

AT. 303

Figure 10-1.—Altimeter Set Electronic, AN/APN-120, simplified block diagram.

required to develop frequencies representative of altitude. The 400-Hz modulation is used to develop an error voltage when a difference exists between the altitude indicated by the returning RF energy and the altitude indicated on the altitude readout. When an error voltage is developed, the servoloop corrects the indicator to agree with the radar return.

In the transmitting portion of the low altitude loop, a 25-kHz signal is generated by an oscillator and modulated by a 400-Hz voltage from the aircraft supply. This complex signal is routed from the amplifier-modulator-oscillator subassembly to the repeller of the klystron, thereby varying the klystron frequency of oscillation. The modulated RF is fed through a directional coupler to the low altitude transmitter antenna. A portion of this signal is also fed back to the modulator, mixed with the repeller supply voltage, and used as a deviation signal.

The low altitude receiving antenna receives the signal reflected from the ground and feeds it to a frequency mixer. A sample of the transmitted signal is also routed (through a frequency translator) to the mixer. The input frequency of the translator is shifted so that the output is 262.5 kHz above the input frequency. The frequency translator provides a local oscillator signal for the mixer. The mixer output is a 262.5-kHz signal with sidebands corresponding to the frequency modulation on the received signal. Since the FM component of the received signal is 25 kHz, sidebands occur at multiples of 25 kHz away from the center frequency. This composite signal is then fed to the 212.5-kHz IF amplifier.

The maximum gain of the IF amplifier is governed by a gain control voltage from the servoloop, so that the gain is a function of altitude. The output of the amplifier programer unit is detected and filtered to produce an AM component and a d-c component. The d-c component provides the automatic gain control voltage and an indication of reliability. The AM component is compared with the aircraft 400-Hz reference to produce a correctional signal for the height indicator.

HIGH ALTITUDE MEASUREMENT LOOP.–The transmitting portion of the high altitude system begins at the range computer. This stage initiates a trigger pulse at a stable repetition rate. The trigger pulse is used in the radar modulator to time and trigger the pulse forming circuits which pulse modulate the transmitter. The modulator also supplies a negative blanking voltage (synchronized by the same trigger) to the electronic gate.

The transmitter oscillator is fired by the modulator pulse, and supplies an RF pulse at approximately 4225 MHz to the antenna arrays. When the transmitted pulse is reflected from the terrain, a portion of the reflected wave is intercepted by the receiving antennas and becomes the received signal.

The received signal is fed into the high altitude frequency mixer. The CW oscillator generates an RF voltage at 4165 MHz for use as the local oscillator signal. In the mixer, the received signal (4225 MHz) beats with the local oscillator signal (4165 MHz) to produce an IF signal of 60 MHz.

The gain of the IF amplifier is regulated by an AGC voltage. During transmit time, gain is reduced to almost zero by a blanking pulse from the electronic gate. This blanking pulse prevents self-triggering by the system's own transmitter. After amplification, the IF signal is detected to produce a video pulse.

The video pulse is gated, timed, and shaped in the programer unit to produce the altitude indication for comparison with the altitude reading on the indicator. Any difference between these values produces an error signal for the servoloop, which then corrects the reading of the instrument.

PROGRAMER.–The programer is common to both the low altitude and the high altitude systems. The programer is made up of circuits, which are partly interdependent in their operation, and performs the following functions which are not discussed in detail:

1. To process the d-c error signals (for low and high altitude range) to provide the required driving signal voltage for the respective servomotor.
2. To perform the required switching functions according to operational mode selection.
3. To provide automatic turn-on of the low altitude system when the altitude is less than 4,000 feet.

4. To provide time-sharing pulses which cause the two systems to alternate their "on" time whenever both systems are operating and the aircraft is at an altitude between 0 and 4,000 feet.

5. To provide the automatic high altitude indicator changeover from radar altitude to barometric altitude in the event of system failure.

RADAR ALTIMETER AN/APN-141(V)

Electronic Altimeter Set AN/APN-141(V) is a pulsed, rangetracking radar that locks onto the leading edge of the echo pulse. It provides a continuous, highly accurate indication of absolute altitude from 0 to 5,000 feet above water or terrain. The accuracy and the reliability make possible extremely low altitude instrument flight missions in familiar or level territory. It also increases the safety of moderately low-level instrument flight missions into territory where the barometric pressure and terrain elevation data are unreliable or unknown.

The equipment consists of the radar transmitter-receiver unit, an RF switching unit, a height indicator, and two antennas.

Characteristics

Altitude information is continuously displayed, in feet of absolute altitude, on a panel-mounted indicator. This information is developed by radiating pulses of microwave energy downward and by monitoring the time required for the return of each pulse as an echo. Monitoring of pulse transit time is accomplished by means of a leading-edge electronic tracking loop which, in effect, locks onto the range of the water or terrain, and follows variations of clearance resulting from aircraft maneuvers or terrain elevation.

Leading-edge tracking provides for an indication of the nearest terrain under the aircraft, and not necessarily the terrain directly under it. Thus, the altimeter set will track a mountainside or a cliff ahead or to the side of the aircraft if this terrain is closer than the ground directly below the aircraft. This feature provides essential warning of rapidly decreasing absolute altitude on low-level missions.

The system has two altitude modes of operation—one for low altitudes and one for high altitudes. At low altitudes (0 to 195 feet ascending and 165 to 0 feet descending), a very narrow, low-powered transmitted pulse is utilized to obtain maximum range resolution. The low altitude pulse is also programed in width to provide the proper strength of the ground return signal with altitude variation. At altitudes above the ascending and descending upper altitude limits, a wider high-power transmitted pulse is utilized to obtain sufficient ground return energy for tracking.

The altimeter system also has two ranging modes of operation—the search mode and the tracking mode. In the search mode, the system successively examines increments of range with each cycle of operation until the complete altitude range is searched for a ground return signal. When the altitude range is found, the system switches over to the tracking mode of operation. In the tracking mode, the system locks onto and tracks the leading edges of the ground return pulses and presents continuous altitude information.

Altitude information is obtained by measuring the time intervals from the instant that each pulse of RF energy leaves the transmitter until the leading edge of the ground return signal is detected in the receiver. The system converts this time interval information to a d-c range voltage which is offset in amplitude to form an altitude d-c voltage analog. This analog is fed to the height indicator which indicates altitude in feet proportional to the amplitude of the d-c voltage.

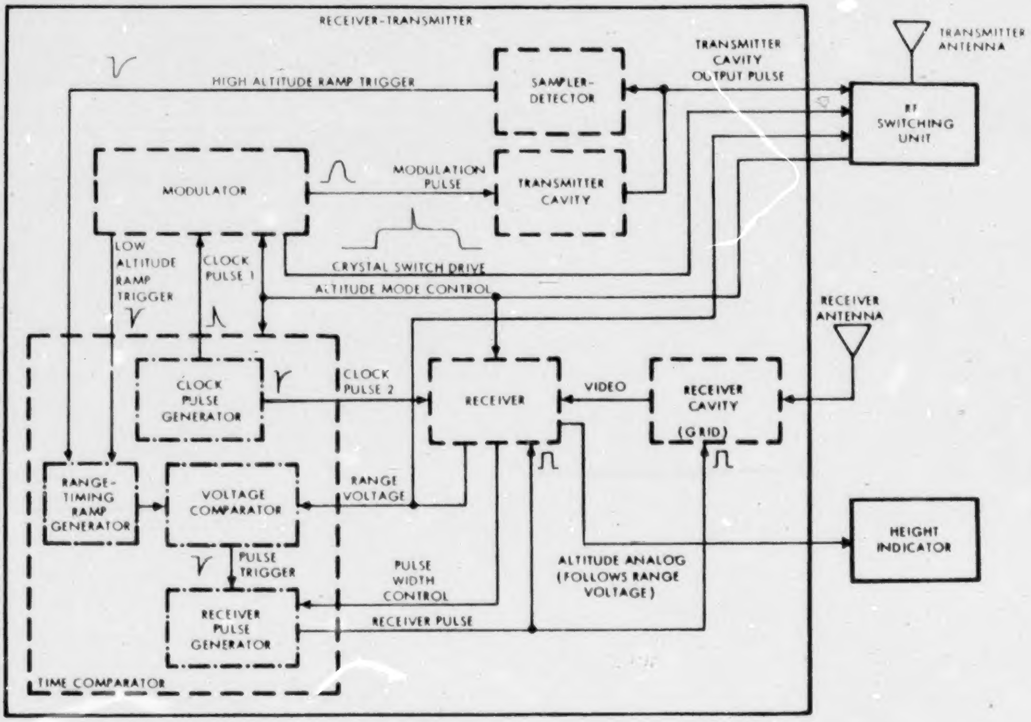
Theory of Operation

For the following general discussion of the theory of operation for Electronic Altimeter Set AN/APN-141(V), refer to figure 10-2. For more detailed information, refer to the applicable technical manuals.

TRANSMISSION.—Clock pulse 1 functions as the basic system timing trigger. This pulse is generated at a 3 kHz rate in the time comparator and is fed to the modulator where it triggers each transmission and cycle of operation. The modulator pulses the transmitter cavity and produces a crystal switch drive signal for gating the narrow RF pulse transmitted during low altitude operation. This gating is accomplished in the RF switching unit. The modulator also produces a range-timing ramp trigger for use in the time comparator during low altitude operation. The modulation pulse drives the transmitter cavity into oscillation, and the transmitter cavity energy is applied to the RF switching unit. A detected sample of the energy is taken from the cavity as a range-timing ramp trigger for use in the time comparator during high altitude operation.

The RF switching unit is controlled by the d-c level of the range voltage input from the receiver, and performs two basic functions: gating of the peak power and width of the transmitted pulse, and switching of the potential on the altitude mode control line. During high altitude operation, the unit routes the full 1-kilowatt output of the transmitter cavity directly to the transmitter antenna and grounds the altitude mode control line. During low altitude operation, the unit attenuates, narrows, and programs the width of the cavity output pulse before application to the antenna. It also places a positive voltage on the altitude mode control line. The potential on the altitude mode control line enables or inhibits circuits in the modulator, time comparator, and receiver to provide the proper gating and timing in these three modules for each altitude mode.

RECEPTION. The receiver antenna senses ground return signals and applies these pulses of RF energy to the receiver cavity. The receiver cavity is a superregenerative detector that generates an output only when pulsed by a positive grid signal. This signal is supplied by the receiver pulse generator in the time comparator. The cavity generates an output each time the receiver pulse is applied, but this output is of greater peak amplitude when ground return energy is


RECEIVER-TRANSMITTER
HIGH ALTITUDE RAMP TRIGGER
SAMPLER-DETECTOR
TRANSMITTER CAVITY OUTPUT PULSE
TRANSMITTER ANTENNA
RF SWITCHING UNIT
MODULATOR
MODULATION PULSE
TRANSMITTER CAVITY
LOW ALTITUDE RAMP TRIGGER
CLOCK PULSE 1
CRYSTAL SWITCH DRIVE
ALTITUDE MODE CONTROL
RECEIVER ANTENNA
CLOCK PULSE GENERATOR
CLOCK PULSE 2
RECEIVER
VIDEO
RECEIVER CAVITY
(GRID)
RANGE-TIMING RAMP GENERATOR
VOLTAGE COMPARATOR
RANGE VOLTAGE
HEIGHT INDICATOR
PULSE TRIGGER
PULSE WIDTH CONTROL
ALTITUDE ANALOG (FOLLOWS RANGE VOLTAGE)
RECEIVER PULSE GENERATOR
RECEIVER PULSE
TIME COMPARATOR

AT. 304

Figure 10-2.–Altimeter AN/APN-141(V), block diagram.

present in the cavity than when this energy is absent.

The receiver pulse is generated twice during each operational cycle first, for detecting the possible presence of ground return energy in the cavity, and later, when no ground return energy can be present for sampling the noise level in the cavity. Either type of cavity output is detected, and resulting high or low amplitude video signal is fed to the receiver. Simultaneously with cavity grid pulsation, the receiver pulse activates the receiver for two brief intervals in the operational cycle.

During the first interval, the receiver examines the video signal for the possible presence of a ground return signal. If the signal is absent, the receiver maintains the system in the search mode of operation. If the signal is present, the receiver switches the system over to the tracking mode.

During the second interval, the receiver samples the noise level in the cavity and utilizes the low amplitude video input to regulate the width of the receiver pulse for the automatic stabilization of receiver gain.

The receiver also utilizes its range voltage output to regulate the width of the receiver pulse for the adjustment of receiver sensitivity to ground return pulses with variations in altitude. Clock pulse 2, from the time comparator, triggers a circuit in the receiver that generates the receiver pulse width control signal.

SEARCH MODE OPERATION. Figure 10-3 shows the idealized basic waveforms and time relationships involved in altitude acquisition and tracking. The (A) set of waveforms is common to both modes, and shows the basic timing and transmission references. The (B) set of waveforms applies to the search mode of operation, and the (C) and (D) sets apply to the tracking mode. The 3-kHz pulse repetition frequency of clock pulse 1 establishes a basic system period of approximately 333 microseconds for both the high and low altitude modes of operation. The signals and events required for altitude acquisition and tracking occur during the first 10 microseconds of this period over the interval of the range-timing ramp. (Since a radar time of 2 microseconds is approximately equivalent to an altitude of 1,000 feet, this first 10-microsecond timing interval corresponds to the 5,000 foot maximum altitude capability of the system.)

In the search mode, the range voltage from the receiver is a freerunning sweep of 2.5-second duration. The range-timing ramp and the range voltage sweep are both fed to a voltage comparator in the time comparator. When voltage coincidence of the ramp and range sweep occurs, the voltage comparator triggers the receiver pulse. The receiver pulse biases the receiver cavity into conduction and triggers a gate in the receiver that momentarily enables amplification and switching circuits to examine an increment of altitude. With no ground return signal present, the receiver cavity generates a small video signal that results from the buildup of the noise level in the conducting cavity.

The equal intervals in the first train of ground return signals shown in figure 10-3(B) represent the pulses present in the receiver cavity at a constant altitude. Over successive cycles of operation, the receiver pulse approaches the ground return pulse in time because of the successive delays in ramp and range sweep voltage coincidence. Throughout a complete 2.5-second range voltage sweep, the receiver pulse is generated approximately 7,500 times, and the altitude is effectively probed in increments of 1 foot. When the receiver pulse reaches the ground return signal in time, the video output from the receiver cavity builds up considerably above the previous levels attained by noise buildup, and switches the receiver from the search to the tracking mode of operation. The video input is then used as a range voltage amplitude control, resulting in the leveling of the range voltage at an amplitude equivalent to the time interval between the transmitted and ground return pulses.

TRACKING MODE OPERATION. When switched over to the tracking mode, the receiver and the time comparator operate together to time the occurrence of the receiver pulse with a point on the slope of the leading edge of the ground return pulse. (See fig. 10-3(C).) With a constant altitude and a consequent steady range voltage, as well as fixed ground return period, this synchronism is merely coincidental. The automatically controlled synchronism required for following altitude changes is provided by a tracking servoloop consisting of the same basic components used in the search mode (switched to the tracking mode of operation).

In the tracking mode, the range voltage still tends to rise, but with a much shallower slope than in the search mode. The tracking servoloop utilizes both this slight tendency of the range voltage to rise if uncontrolled and the sensitivity and power buildup characteristics of the receiver cavity as a governing mechanism for locking onto and tracking altitude changes. At the leading edge of the receiver pulse, cavity sensitivity rises sharply to a maximum value and then falls off exponentially to a zero value near the trailing edge of the grid pulse.

The center column of curves in figure 10-3(D) shows the operation of this governing mechanism at a constant altitude. Here the leading edge of the grid pulse is timed to coincide with a nominal power level on the leading edge of the ground return pulse. The point of maximum cavity sensitivity coincides with this nominal RF power level. The buildup of cavity output power, because of the exponential curve of the sensitivity characteristic, is linear. Averaged over succeeding cycles of operation, the buildup is just sufficient to keep the range voltage at a constant level, maintaining a constant period of ramp and range voltage coincidence and a consequent fixed grid-pulse spacing. The results are a steady d-c voltage analog to the height indicator and a constant altitude indication.

The lower set of waveforms in figure 10-3(C) shows how the system tracks a ground return pulse train whose period shortens successively with decreasing altitude. The second receiver pulse, whose spacing from the first pulse is governed by the previous coincidence of ramp and range voltage, occurs slightly delayed with respect to the ground return pulse. Receiver cavity buildup of video output power increases and drives down the range voltage and altitude analog. This causes range and ramp voltage coincidence to occur earlier and the receiver pulse to follow the leading edge of the ground return pulse.

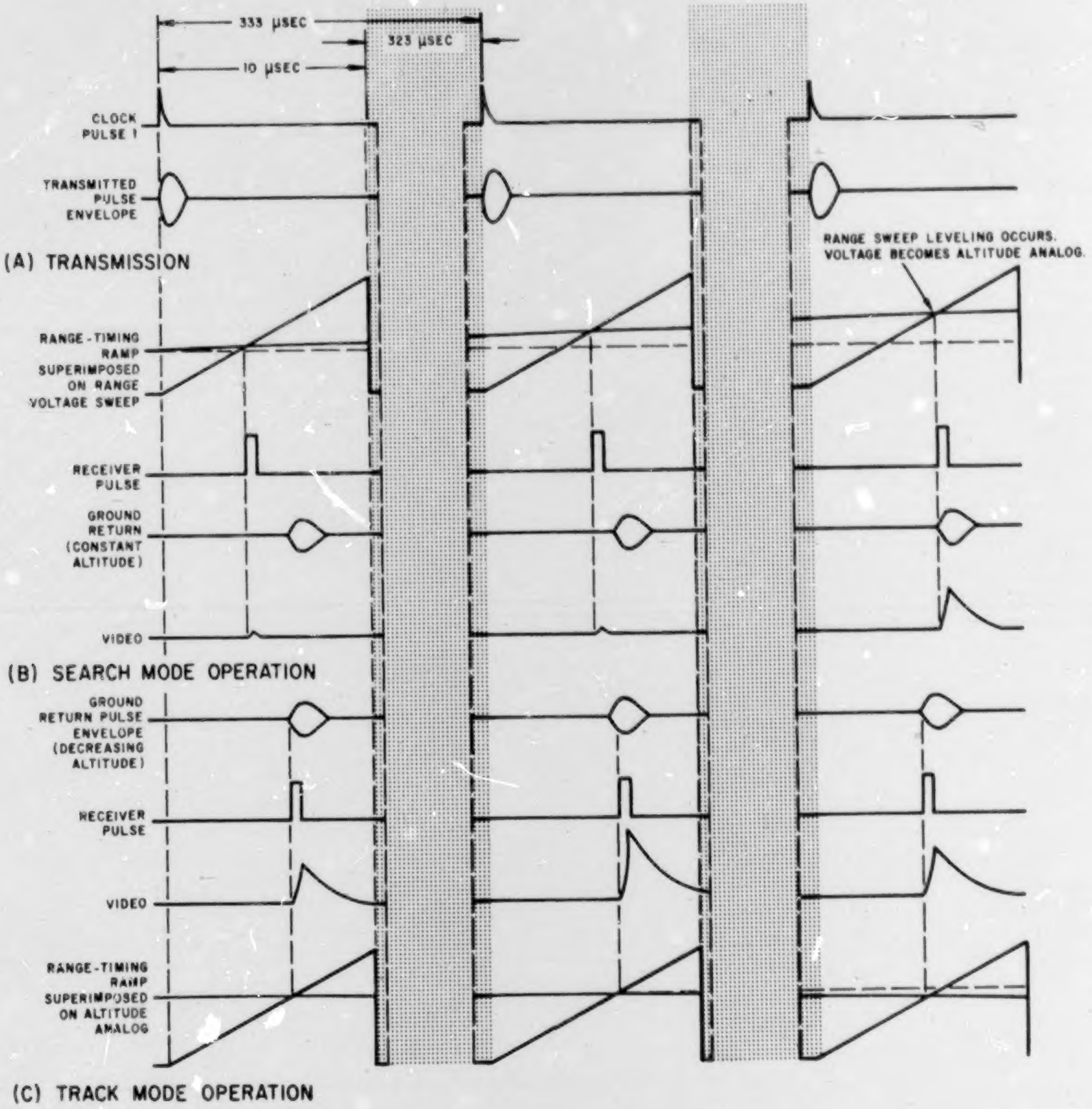
The left column of curves in figure 10-3(D) shows the operation of the tracking servoloop with a decreasing altitude (or with any tendency of the grid-pulse spacing to drive toward a longer period than that required for tracking). The ground return pulse arrives slightly earlier than for a constant altitude, and the leading edge of the grid pulse coincides with a higher power level on the leading edge of the ground return pulse. The consequent higher peak buildup of cavity output power, averaged over a number of operational cycles, drives the range voltage and altitude analog down.

The right column of curves in figure 10-3(D) shows the operation with increasing altitude (or with any tendency of the grid-pulse spacing to drift toward a shorter period than that required for tracking). The ground return pulse arrives slightly later than for a constant altitude, and the leading edge of the grid pulse coincides with a lower power level. The consequent lower peak buildup of cavity output power, averaged over a number of cycles, allows the range voltage and altitude analog to rise. Thus, the time coincidence of the ramp and range voltage, controlled by the amount of peak video power developed from the initial level of RF signal power at the leading edge of the grid pulse, adjusts the spacing of the receiver pulse automatically to track the leading edge of the ground return pulse. The resulting altitude analog, which follows the range voltage, thus tracks a balance of two opposing forces–the tendency of the range voltage to rise as the output of a shallow sweep generator, and the force of the average video power that drives the outputs of the sweep generator down.

ALTITUDE INDICATION.–The height indicator is a servo-driven device that positions the pointer at an altitude proportional to the d-c voltage analog from the receiver. In addition, the indicator provides two alerting functions. An OFF flag comes into view in the center of the indicator dial whenever the altimeter is not tracking a ground return signal. A low altitude warning system, which can be set to any altitude from 0 to 5,000 feet, causes a red warning light (in some aircraft installations) on the aircraft instrument panel to illuminate when the aircraft descends below the preset altitude.

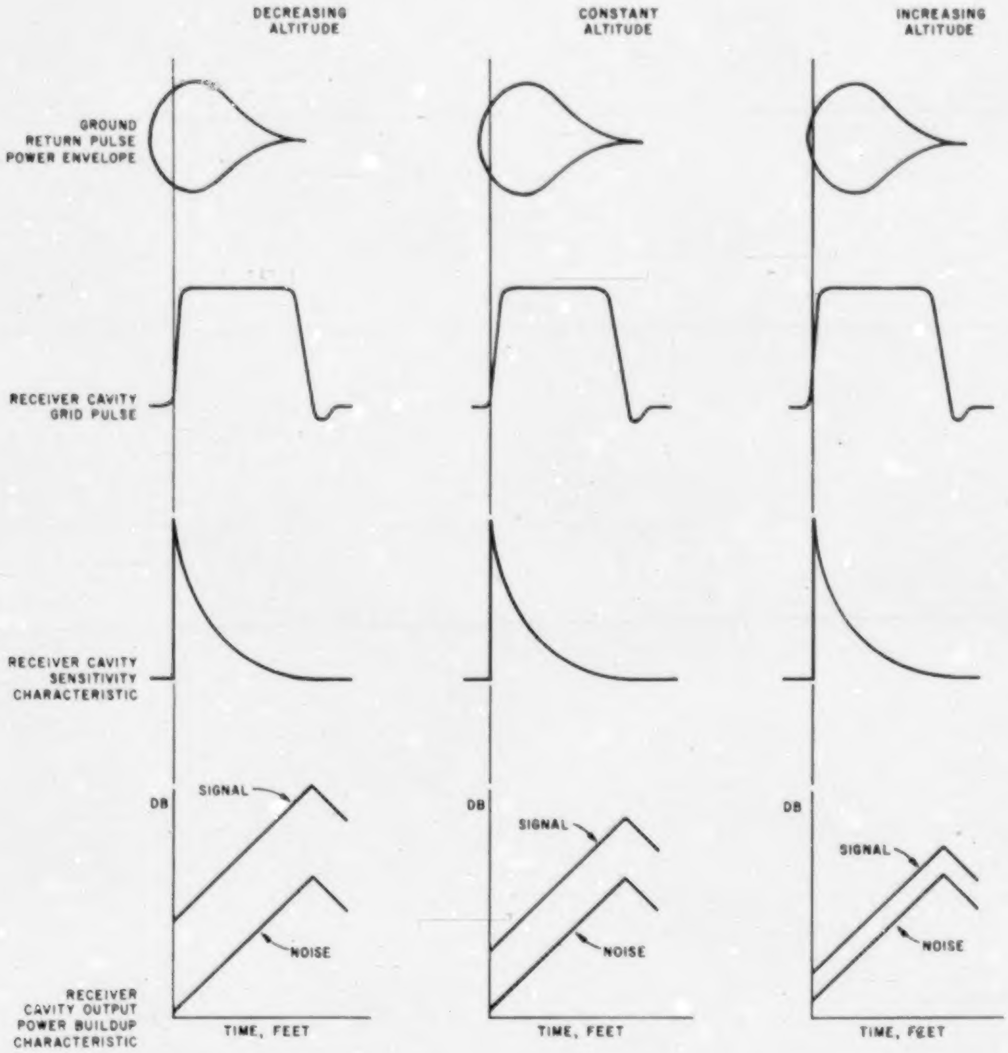
BENCH TEST AND CALIBRATION

Most of the later electronic altimeters require the use of a specific test set that is designed only


333 μSEC
323 μSEC
10 μSEC
CLOCK PULSE 1
TRANSMITTED PULSE ENVELOPE
(A) TRANSMISSION
RANGE SWEEP LEVELING OCCURS. VOLTAGE BECOMES ALTITUDE ANALOG.
RANGE-TIMING RAMP SUPERIMPOSED ON RANGE VOLTAGE SWEEP
RECEIVER PULSE
GROUND RETURN (CONSTANT ALTITUDE)
VIDEO
(B) SEARCH MODE OPERATION
GROUND RETURN PULSE ENVELOPE (DECREASING ALTITUDE)
RECEIVER PULSE
VIDEO
RANGE-TIMING RAMP SUPERIMPOSED ON ALTITUDE ANALOG
(C) TRACK MODE OPERATION

AT. 305

Figure 10-3.—Basic system timing sequence.


DECREASING ALTITUDE
CONSTANT ALTITUDE
INCREASING ALTITUDE
GROUND RETURN PULSE POWER ENVELOPE
RECEIVER CAVITY GRID PULSE
RECEIVER CAVITY SENSITIVITY CHARACTERISTIC
DB
SIGNAL
NOISE
DB
SIGNAL
NOISE
DB
SIGNAL
NOISE
RECEIVER CAVITY OUTPUT POWER BUILDUP CHARACTERISTIC
TIME, FEET
TIME, FEET
TIME, FEET

(D) TRACKING SERVOLOOP

AT. 306

Figure 10-3.–Basic system timing sequence–Continued.

for that particular model altimeter. Some altimeters are a part of a larger navigation system and have the advantage of being checked for operation and calibration while installed in the aircraft by the use of the aircraft system computer.

Other altimeter types can only be checked in the aircraft by the use of a test set commonly known as a "GO-NO GO checker." This test set is normally a fixed delay line. Test sets of this type are discussed under line test equipment in chapter 5 of this manual.

Shop test equipments (Avionics Test Sets AN/ASM-93(XN-1) for use ashore and AN/ASM-94(XN-1) for use at sea) are used in the shop to isolate troubles in the electronic system components (removed from the aircraft) to a module level or to a specific area within the component. The above named electronic test equipments also have the capability of locating trouble within themselves to a module level. This support equipment may also be used to provide a rapid before-flight confidence check of the altimeter (or other avionics systems) in the aircraft.

The AN/APN-141(V) also has its own bench test set, Altimeter Test Bench Set TS-1979A/APN-141(V) (fig. 10-4). Any time that maintenance is to be performed on either the transmitter-receiver or the RF switching unit, both units must be calibrated as a matched pair with the bench test set. The AN/APM-348 provides facilities for testing the electronic altimeter set sensitivity and accuracy and has fault isolation capability when testing an altimeter set which is installed in an aircraft.

Earlier altimeters, such as the AN/APN-22 and AN/APN-117, utilize the Radar Test Set AN/APM-66. This test set also provides a means of calibrating, checking the operation, and facilitating the maintenance of both sets. A unit of this test set (Delay Line MX-1381/APM-66) provides a "GO-NO GO" test for line maintenance of either altimeter. The electronic control amplifiers and the transmitter-receiver units must be calibrated on the test bench as a matched set for proper operation in the aircraft.

RADAR ALTIMETER WARNING SYSTEM

The Radar Altimeter Warning Set (RAWS) AN/APQ-107 is used in conjunction with altimeters such as Radar Altimeter AN/APN-117, Radar Altimeter AN/APN-22, or the Electronic Altimeter AN/APN-141 previously discussed. It provides aural and visual warning signals to the pilot and copilot when any of three unsafe flight conditions exist:

1. Aircraft flies below preselected altitudes.
2. Input power to the radar altimeter fails.
3. Radar altimeter warning circuit indicates unreliability.

Functional Characteristics

The RAWS receives a signal which is a function of altitude from a radar altimeter. When the aircraft descends to a preselected altitude (designated "high altitude index"), the incoming altimeter signal is interpreted by the warning set. The RAWS produces a signal that causes warning lamps to flash in the cockpit, and a concurrent 1000-hertz interrupted tone signal is heard in the pilot's and copilot's headsets. Both the aural and visual signals are repeated twice a second for a duration of 3 seconds. No further warning indications are supplied until the aircraft descends to a preset "low altitude index." When the low altitude index is reached, a warning is indicated by the warning lamps and an interrupted 1000-hertz tone sounds in the headsets again. These warning signals continue as long as the aircraft remains below the low altitude index setting. When the aircraft ascends through the high altitude index setting, the warning signals are not presented.

Figure 10-5 shows the AN/APQ-107. It is important to note that the high and low index settings and the type of aircraft for which the RAWS has been precalibrated are indicated on the front of the set.

In addition to the altitude index warnings, the power failure (115-v, 400-Hz a.c., or 28-v d.c.) to the radar altimeter indicator causes the warning set to produce aural and visual warning indications at a two-times-per-second rate. Another hazardous flight condition which will cause the set to produce warning signals is when the radar altimeter becomes unreliable. This condition could be caused by either the radar receivers' signal being too weak to provide reliable altitude information, or if the altimeter itself malfunc-

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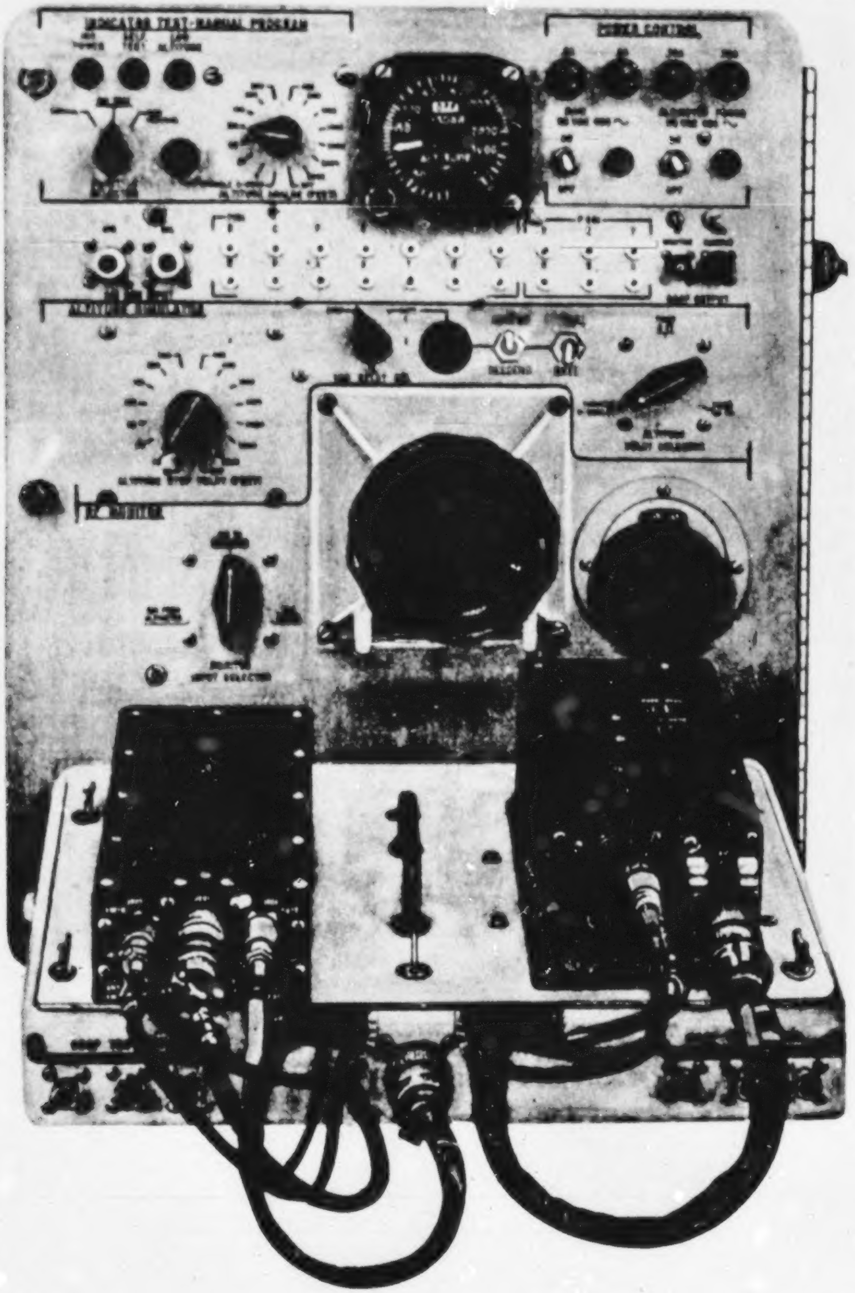
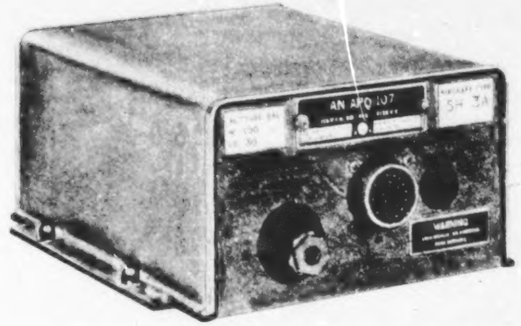

INDICATOR TEST-MANUAL PROGRAM
POWER CONTROL

AT. 325

Figure 10-4.–Altimeter Test Bench Set, TS-1979A/APN-141(V).



AT. 326

Figure 10-5.—Radar Altimeter Warning Set, AN/APQ-107.

tions. These warning signals, however, may be altered by a flight or altitude inhibit condition.

WARNING INHIBIT CONDITIONS.—A warning inhibit (overriding) condition is a flight or altitude situation that applies a bias potential to a diode gate, altering one or more signals or indications transmitted by the warning set. Refer to figure 10-6 throughout the remainder of this discussion.

The following conditions inhibit warning signals as indicated:

1. When all wheels are down and locked (pins C, B, and Z), the low altitude index audible signal is inhibited (pins G, H, K, and L).
2. When the wheels are down and locked (pins C, B, and Z) and the altimeter is unreliable (pin E), both the audible and visual signals (pins G, H, K, L, and F) are inhibited.
3. Aircraft operation at a barometric altitude over 700 feet (referenced to takeoff altitude) (S-2), together with an unreliable altimeter (pin E), inhibits the high altitude index, low altitude index, and unreliability warning indications (pins G, H, K, L, and F).
4. When automatic stabilization equipment (ASE) is engaged (pin D), the 3-second high altitude index warning is inhibited (pins G, H, K, L, and F). This condition has no effect on the low altitude index warning or altimeter limit indicator warning.

NOTE: In aircraft where it is desirable to have the pilot and/or copilot adjust the critical altitude setting with the radar altimeter limit indicators, the low altitude index is provided by the limit indicator setting (pins n and p). The low altitude index warning signal is produced when the aircraft is flying below the limit set by the pilot's and/or copilot's limit indicator (UH-2 aircraft only).

5. A weight-on-wheels condition (pin q) inhibits the aural portion (pins G, H, K, and L) of the power failure warning (input pin M). All other inputs to the RAWS are overridden by a power failure warning input.
6. With proper external connections, the wheels down and lock condition (UH-2 aircraft only) will inhibit the high altitude index warning indications (pins G, H, K, L, and F).

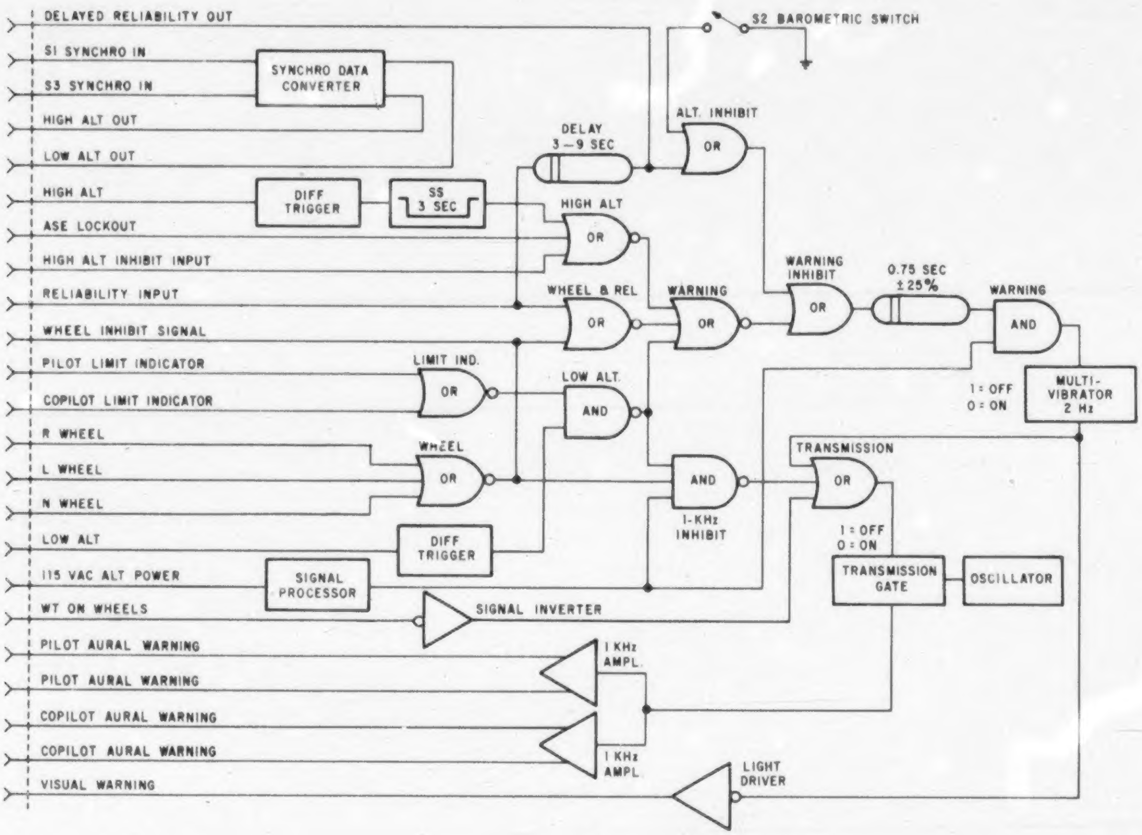
Test and Calibration

While calibration and adjustment of the warning set are beyond the scope of organizational activities, a performance test with the equipment in the aircraft may be accomplished without the use of test equipment. The radar altimeter must be operating and in the reliable condition during the test. The test procedure is as follows:

1. Depress the TEST button on the front panel of the warning set (fig. 10-5) or the RAWS self test switch in the cockpit. The 1000-hertz tone should be heard in the pilot's and copilot's headsets. The cockpit warning lamps should flash in synchronization with the aural pulses. Release the test button, and the indications should cease.
2. Deenergize the 115-volt, 400-hertz a-c power input to the radar altimeter to initiate the visual warning indication. There should be no aural warnings.

AN/APM-254.—This test set (fig. 10-7) is used to calibrate, troubleshoot (fault isolation), and perform operational checks on Radar Altimeter Warning Set AN/APQ-107 (RAWS). The test set can be used either as a bench tester or on the flight line to test installed warning sets.

The test set supplies power to operate the RAWS and output signals which simulate the altitude signals from the AN/APN-22, AN/APN-


DELAYED RELIABILITY OUT
S1 SYNCHRO IN
S3 SYNCHRO IN
HIGH ALT OUT
LOW ALT OUT
HIGH ALT
ASE LOCKOUT
HIGH ALT INHIBIT INPUT
RELIABILITY INPUT
WHEEL INHIBIT SIGNAL
PILOT LIMIT INDICATOR
COPILOT LIMIT INDICATOR
R WHEEL
L WHEEL
N WHEEL
LOW ALT
115 VAC ALT POWER
WT ON WHEELS
PILOT AURAL WARNING
PILOT AURAL WARNING
COPILOT AURAL WARNING
COPILOT AURAL WARNING
VISUAL WARNING
SYNCHRO DATA CONVERTER
S2 BAROMETRIC SWITCH
ALT. INHIBIT
OR
DELAY 3 – 9 SEC
DIFF TRIGGER
SS 3 SEC
HIGH ALT
OR
WHEEL & REL
OR
WARNING
OR
WARNING INHIBIT
OR
0.75 SEC ±25%
WARNING
AND
LIMIT IND.
OR
LOW ALT.
AND
1 = OFF
0 = ON
MULTI-VIBRATOR 2 Hz
WHEEL
OR
AND
1-KHz INHIBIT
TRANSMISSION
OR
1 = OFF
0 = ON
DIFF TRIGGER
SIGNAL PROCESSOR
TRANSMISSION GATE
OSCILLATOR
SIGNAL INVERTER
1 KHz AMPL.
1 KHz AMPL.
LIGHT DRIVER

AT. 327

Figure 10-6.—Logic diagram, general system operation.

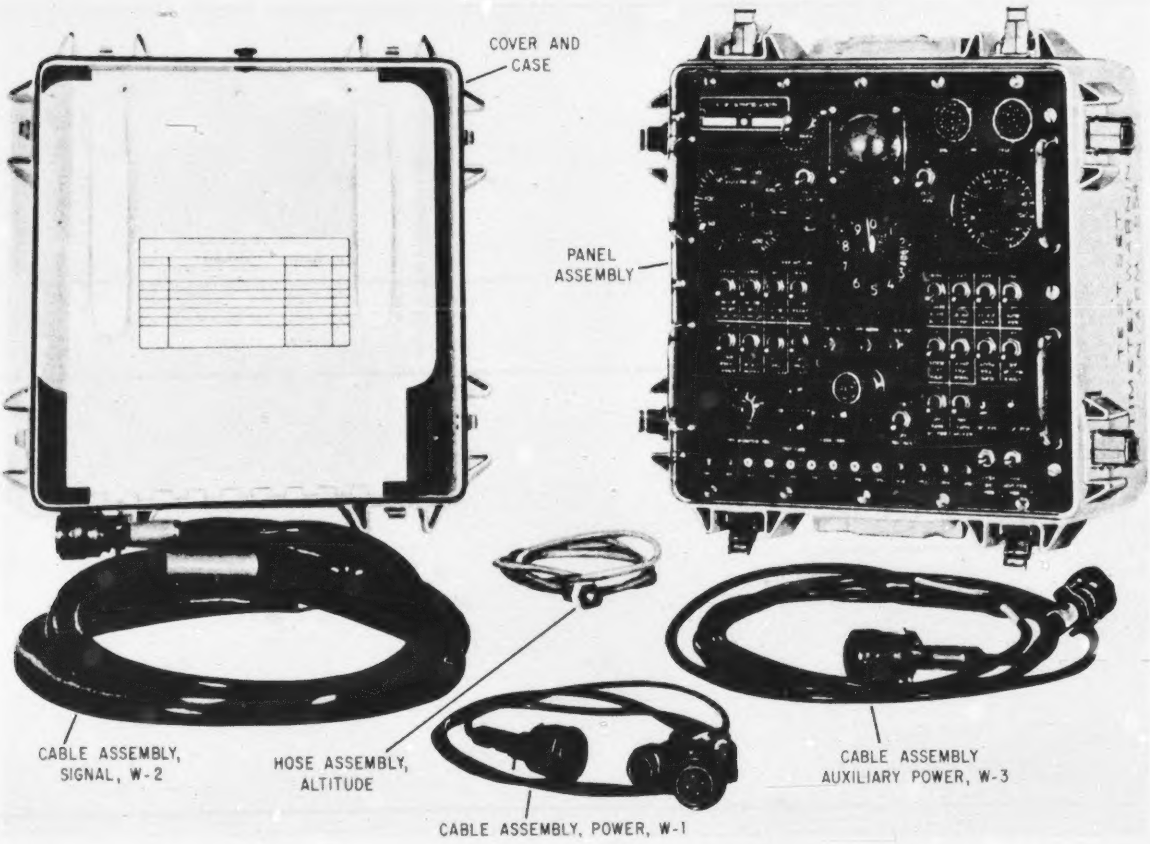
117, or AN/APN-141 radar altimeter. In addition, the test set provides output signals simulating the various enabling and disabling aircraft signals, a means of monitoring the output signal from the RAWS, and a simulated barometric altitude of up to 7,000 feet. The test set also has a self-test feature which should always be performed prior to checking the RAWS system.

RADIO RANGES AND RELATED FACILITIES

A radio range is a facility whose radiation patterns produce directional courses or "tracks" by having special characteristics in its emissions recognizable as bearing information. These courses remain stationary with respect to the surface of the earth, and serve to guide aircraft over long distances.

OMNIDIRECTIONAL RANGE

As the name VOR (VHF, omnidirectional range) implies, the omnidirectional or all-directional range station provides the pilot with courses from any point in its service area. It produces an unlimited number of radials, any one of which is a radio path connected to the station. The radials should be considered as lines which originate at the station and radiate outward like the spokes of a wheel. Operation is in


COVER AND CASE
PANEL ASSEMBLY
CABLE ASSEMBLY, SIGNAL, W-2
HOSE ASSEMBLY, ALTITUDE
CABLE ASSEMBLY, POWER, W-1
CABLE ASSEMBLY AUXILIARY POWER, W-3

AT.328

Figure 10-7.—Altimeter Warning Test Set AN/APM-254.

the VHF portion of the radio spectrum with the result that interference from atmospheric and precipitation static is negligible. The navigational information is presented in a visual form, is constantly available, and is provided regardless of the position of the aircraft in the service area.

The basic provision of the VOR facility is a means of determining the angular position, or azimuth, of an aircraft with respect to the station. This measurement is made in the airborne receiver which determines the phase difference of two 30-hertz tones derived from two signals radiated from the range station transmitting antenna array. One signal, called the reference phase, is broadcast in a nondirectional radiation pattern. At all points on a circle having the station as its center, corresponding parts of this 30-hertz modulation occur at exactly the same time. Since the phase of this signal is independent of azimuth, it is used as a reference for comparison with another 30-hertz variation derived from a signal called the variable phase.

The variable phase signal is radiated in a figure-of-eight pattern which revolves about the transmitting antenna in a way somewhat similar to a rotating searchlight beam. The pattern consists of a positive and a negative lobe which turn together at 1,800 rpm (30 rps). The equipment is designed so that the 30-hertz frequency-modulated component reaches its positive maximum at the same time that the rotating pattern maximum passes magnetic north. As a result of the rotation of the pattern, the signal induced in the receiver is amplitude modulated with 30-hertz variations. The receiver develops this tone and compares it with the reference signal. The amount of phase difference between the two depends on the location of the aircraft with respect to the station. A phase measuring circuit in the receiver enables the pilot to determine the magnetic bearing, and also to select and fly a range course to the station on any desired bearing.

As shown in figure 10-8, the VOR transmitter is modulated both by a 9.96-kHz subcarrier and by an additional component either of voice or the station identification code characters. The subcarrier is frequency modulated at 30 Hz and is generated by a notched tone wheel rotating in a magnetic field. The purpose of the subcarrier is to provide a means for separating the 30-hertz tone of the reference phase from the variable tone of the same frequency.

The modulated output of the transmitter is applied to both a modulation eliminator and to the center loop antenna of a five-element array. There it is radiated to form the reference phase signal. The modulation eliminator is a clipper which removes the amplitude modulation from the carrier. The unmodulated output is fed to a capacity goniometer which serves as a mechanical sideband generator. The goniometer is a motor-driven, double capacitor in which one set of stator plates is displaced 90° from the other set. The rotor plates to which the RF signal is applied are driven at 1,800 rpm (30 rps).

Two outputs are derived, one from each set of stator plates. These two signals contain modulation components (30 Hz) which differ in phase by 90° because of the capacitor plate relationship. One output is fed to one pair of diagonally opposite loop antennas, and the other is fed to the remaining pair of loops in the square array. Each pair of corner antennas produces a figure-of-eight radiation pattern. These two patterns are displaced from each other by 90° in both space and time phase. The resultant pattern is the sum of the two crossed figure-of-eight patterns and consists of the rotating field described above.

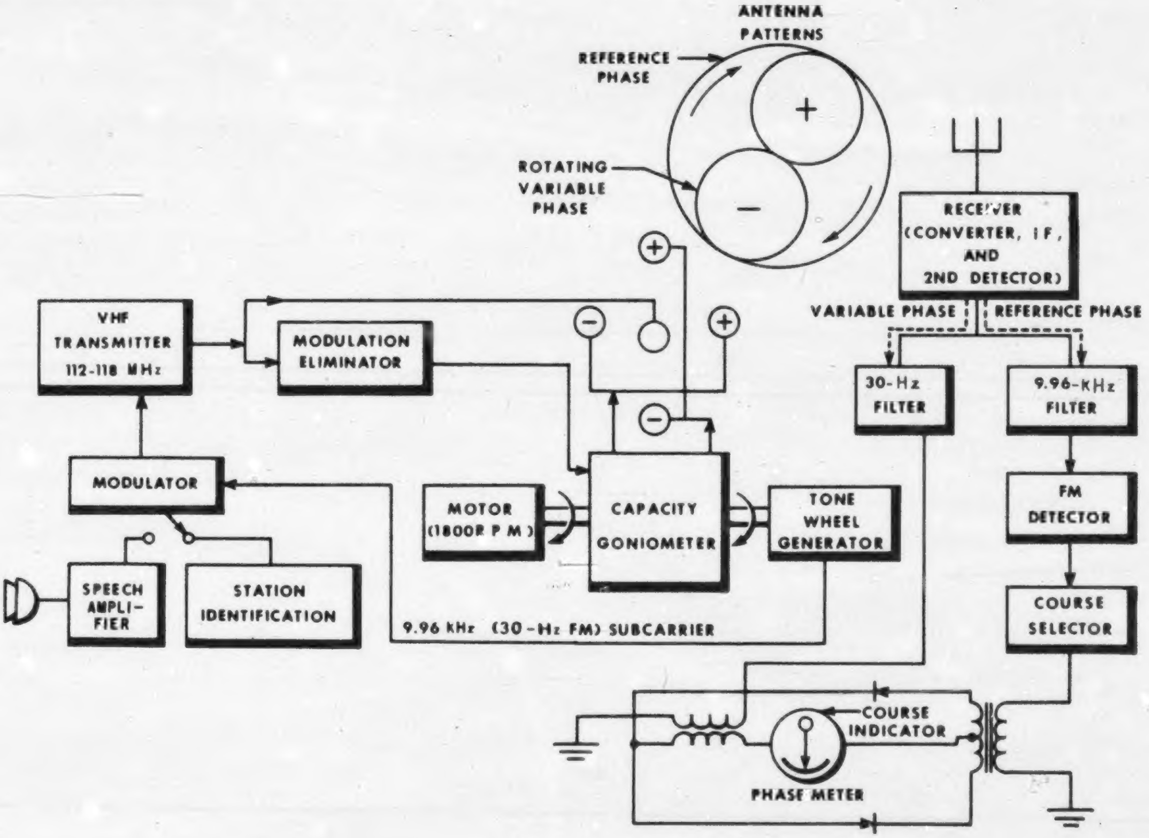
Figure 10-8 shows in simplified form the essential elements of the receiver which enable the pilot to select and fly a range course to the omnidirectional station. In the VOR transmitting system, the reference and the variable signals are in phase along the 0° radial (bearing due north of the station). The phase difference between the signals changes proportionately with the change in bearing to the station. The airborne receiver measures the magnetic bearing of the range station by the following general method:

1. The reference and variable signals are received and separated.
2. The two signals are then applied to a phase bridge containing a zero-center meter (the vertical pointer instrument used with the ILS localizer beam).
3. The reference signal is applied through a phase shifter, or course selector, equipped with a dial calibrated in degrees from 0 to 360.

The reference signal is shifted (in phase) by adjustment of the calibrated course selector until the phase bridge is brought to a zero indication. The amount of phase shift required to zero the bridge is proportional to the magnetic bearing of the range station.

To fly a given course to the station, the pilot sets the phase shifter until the calibrated dial reads the desired course. With this setting the reference signal is phased so that a balanced condition of the course indicator needle is shown as long as the aircraft is on the selected radial. To follow the radial to the station (usually described as "flying inbound"), the pilot flies so as to keep the vertical needle of the course indicator in the center position. The terms radial and course do not always mean the same thing. To fly inbound on the 045° radial, the pilot must fly a course of 225°. To fly inbound on a course of 130°, the pilot must use the 310° radial.

As indicated in figure 10-8, the receiver is an ordinary superheterodyne through the second detector. Following the second detector, filter circuits separate the 9,960-hertz subcarrier and the variable phase 30-hertz signals. The FM subcarrier is then applied to an FM detector which


ANTENNA PATTERNS
REFERENCE PHASE
ROTATING VARIABLE PHASE
+
−
RECEIVER (CONVERTER, I F, AND 2ND DETECTOR)
VARIABLE PHASE
REFERENCE PHASE
VHF TRANSMITTER 112-118 MHz
MODULATION ELIMINATOR
30-Hz FILTER
9.96-KHz FILTER
MODULATOR
MOTOR (1800R P M)
CAPACITY GONIOMETER
TONE WHEEL GENERATOR
FM DETECTOR
SPEECH AMPLIFIER
STATION IDENTIFICATION
9.96 kHz (30-Hz FM) SUBCARRIER
COURSE SELECTOR
COURSE INDICATOR
PHASE METER

AT. 307

Figure 10-8.—Omnirange system fundamentals.

recovers the 30-hertz reference voltage. After passing through the phase shifter (course selector), the reference voltage is combined with the variable signal in the phase meter circuit.

The phase meter is a bridge which is balanced (indicated by a center position of the course indicator) when the two 30-hertz variations applied to it differ in phase by 90°. With this relation, the vector sum of the voltages in the upper half of the circuit is equal to the vector sum of those in the lower half. The two sums are converted into d.c. by rectifiers and applied to the zero-center instrument with opposite polarity.

The phase shifter contains two transformer windings mounted at right angles, and these two are fed with two components of the reference signal. A third winding rotates inside the other two coils, and a voltage is induced in it with a phase angle which depends on the rotor position with respect to the two primaries. The rotor coil is attached to a counter type dial which is calibrated in degrees to indicate the magnetic bearing to the omnirange station. A manually adjustable set knob is used to position the rotor for the desired magnetic course.

The vertical pointer of the course indicator remains in the center as long as the aircraft is on the selected course line, whether inbound or outbound. (This results from the fact that there are two positions of the phase shifter which will balance the bridge circuit.) Since the course line consists of two radials which are reciprocals of each other, an indicator is needed so that the pilot will know which radial (that is, which side of the station) he is on. The TO-FROM indicator tells the pilot whether the selected course line, once he is on it, will take him to the station or from the station.

For example, suppose the aircraft is on the 90° radial. To fly to the station, the pilot takes a heading of 270° and dials 270° on the course selector. The TO-FROM indicator reads TO while the aircraft is approaching the station from the east. After passing over the station, continuing westbound, the TO-FROM indicator reads FROM.

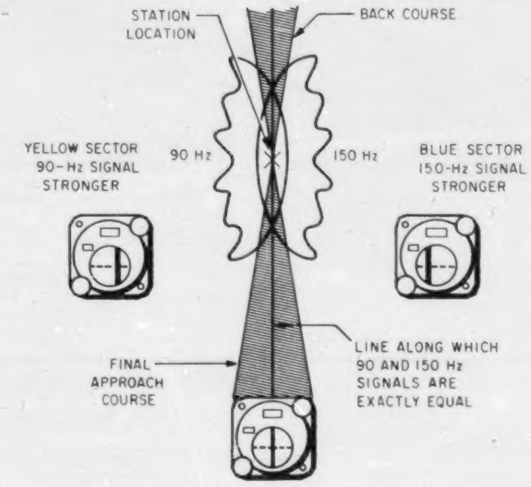
INSTRUMENT LANDING SYSTEM

The instrument landing system (ILS), one of the facilities of the federal airways, operates in the VHF portion of the spectrum. The entire system consists of a runway localizer, a glidepath signal, and marker beacons for position location.

The localizer equipment produces a radio course alined with the center of an airport runway. The on-course signal results from equal reception of two signals–one containing 90 hertz modulation, and the other containing 150 hertz modulation. On one side of the runway centerline, the radio receiver develops an output in which the 150-hertz tone predominates. This area is called the blue sector. On the other side of the centerline, the 90-hertz output is greater. This area is called the yellow sector.

In the aircraft receiver, the output circuit contains a balanced rectifier connected to a zero-center microammeter which remains centered as long as equal amounts of the two tones are present. Deviation of the aircraft to either side of the final approach course results in deviation of the indicator as shown in figure 10-9.

The localizer transmitter operates at about 110 MHZ. The transmissions are made from an antenna array containing eight loops situated about 1,500 feet from the end of the runway. Three kinds of transmissions are made. Six of the loops radiate sideband energy only. Sidebands containing 90-hertz modulation and those bands containing 150-hertz modulation are separated by a sharp null directed along the centerline of the runway. Two of the loops radiate the carrier wave containing equal amounts of 90-hertz and 150-hertz tones, and this signal is sent along the null separating the sectors. Signals are received in any location; but as indicated in the figure, only along the runway centerline are the 90-hertz and 150-hertz tones received in exactly equal amounts.


STATION LOCATION
BACK COURSE
YELLOW SECTOR 90-Hz SIGNAL STRONGER
90 Hz
150 Hz
BLUE SECTOR 150-Hz SIGNAL STRONGER
FINAL APPROACH COURSE
LINE ALONG WHICH 90 AND 150 Hz SIGNALS ARE EXACTLY EQUAL

AT.308

Figure 10-9.–Tone localizer pattern and instrument indications.

The glidepath is a radio beam which gives vertical guidance to the pilot, assisting him in making the correct angle of descent to the runway. Glidepath signals are radiated from two antennas which are driven by a crystal-controlled transmitter operating at about 330 MHz. The power output is about 25 watts.

One antenna radiates a beam which is very broad in the vertical plane. This beam contains signals modulated by a 90-hertz tone. The other antenna emits signals modulated at 150 hertz in many lobes which are very narrow in the vertical plane. The undesired lobes are too high (fig. 10-10) to be encountered in a normal approach.

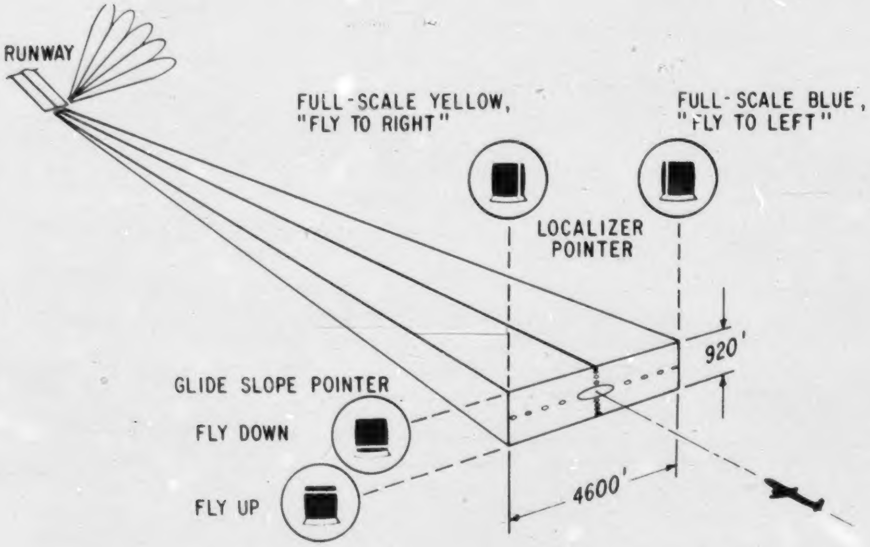
The glidepath is an area of intersection between the broad 90-hertz lobe and the lowest of the 150-hertz lobes. In this area, which is a conical beam, the receiver develops equal amounts of 90-hertz and 150-hertz signals in the output. The beam is inclined about 2.5° with the horizontal.

The glidepath receiver is a crystal-controlled superheterodyne which is powered entirely from a 28-volt, d-c source and requires no high voltage power. The receiver audio output containing the 90-hertz and 150-hertz tones is filtered, and the two signals are rectified separately. The resulting direct current is applied to a zero-center microammeter which indicates by means of a horizontal pointer. (The localizer and glidepath indicators are actually mounted on the same instrument. However, in most military installations the glidepath equipment is not employed.) The pilot flies the glidepath by keeping the horizontal pointer in the center of the dial.

Figure 10-10 shows how the glidepath would appear. The cross section is shown from the runway to a distance of 10 miles. At that range the glidepath appears to be 920 feet thick (vertically) and 4,600 feet wide. By keeping both pointers centered, the pilot may fly to the runway without seeing the ground. However, once over the runway, the pilot must be able to see the runway in order to land.

ILS Marker Beacons

The function of marker beacons is to identify a particular location in space along an airway or on the approach to an instrument runway. The ILS marker beacons are a part of the instrument landing system and are referred to as the outer marker, the middle marker, and the inner marker. These markers are located on the extension of the instrument runway centerline and are used to mark definite positions along the instrument approach course. The outer marker beacon usually marks the intersection of the approach altitude with the glide path, and is modulated at 400 hertz and keyed at two dashes per second. The middle marker indicates a point approximately 3,500 feet from the approach end of the runway, and is modulated at 1300 hertz and



AT. 309

Figure 10-10.—Cross section of ILS course.

keyed with alternate dots and dashes. The dashes are keyed at the rate of 2 per second and the dots at 6 per second. The inner marker, sometimes installed at military airports, marks the beginning of the usable landing area on the airport. It is modulated at 3000 hertz and keyed at 6 dots per second.

ILS marker beacons are crystal controlled transmitters with an output power of approximately 3 watts. The directional antenna array and counterpoise are designed to produce an elliptical pattern which is directed straight upward.

AN/ARN-32 MARKER BEACON RECEIVING SET.–The marker beacon receiver is a 75-MHz, superheterodyne receiver, designed with very high selectivity in order to suppress adjacent frequencies. This insures that undesirable signals will not interfere and cause a false marker beacon display. Reception of the marker beacon is indicated by means of lamps on the instrument panel. In addition, an aural tone is heard on the intercommunication system.

The signal input from the antenna (fig. 10-11) is applied to an antenna input filter which increases the receiver selectivity and also prevents radiation from the local oscillator into the antenna. The 75-MHz input signal is heterodyned in the mixer with the 68.10-MHz output of the local oscillator, producing an intermediate frequency of 6900 kHz. This high intermediate frequency increases the image frequency rejection of the receiver. The second IF amplifier incorporates a varistor (voltage sensitive resistor) in the cathode bias network to compensate for variations in the supply voltage.

The amplified IF signal is then transformer coupled to the demodulator and AVC (automatic volume control) stage. This demodulated audio signal is applied to the first audio amplifier and filtered for application to both the second stage audio amplifier and to the audio rectifier. The rectified signal is filtered and applied to a d-c amplifier, and tnen to an indicator relay which, during signal reception, closes and lights the marker beacon indicator lamps. The amplified audio signal is fed to the aircraft's interphone system.

In conjunction with the marker beacon system, a compass locator transmitter is used to provide signals for automatic direction finding (ADF) equipment. This transmitter continually broadcasts two code initials that identify the airfield.

TACAN

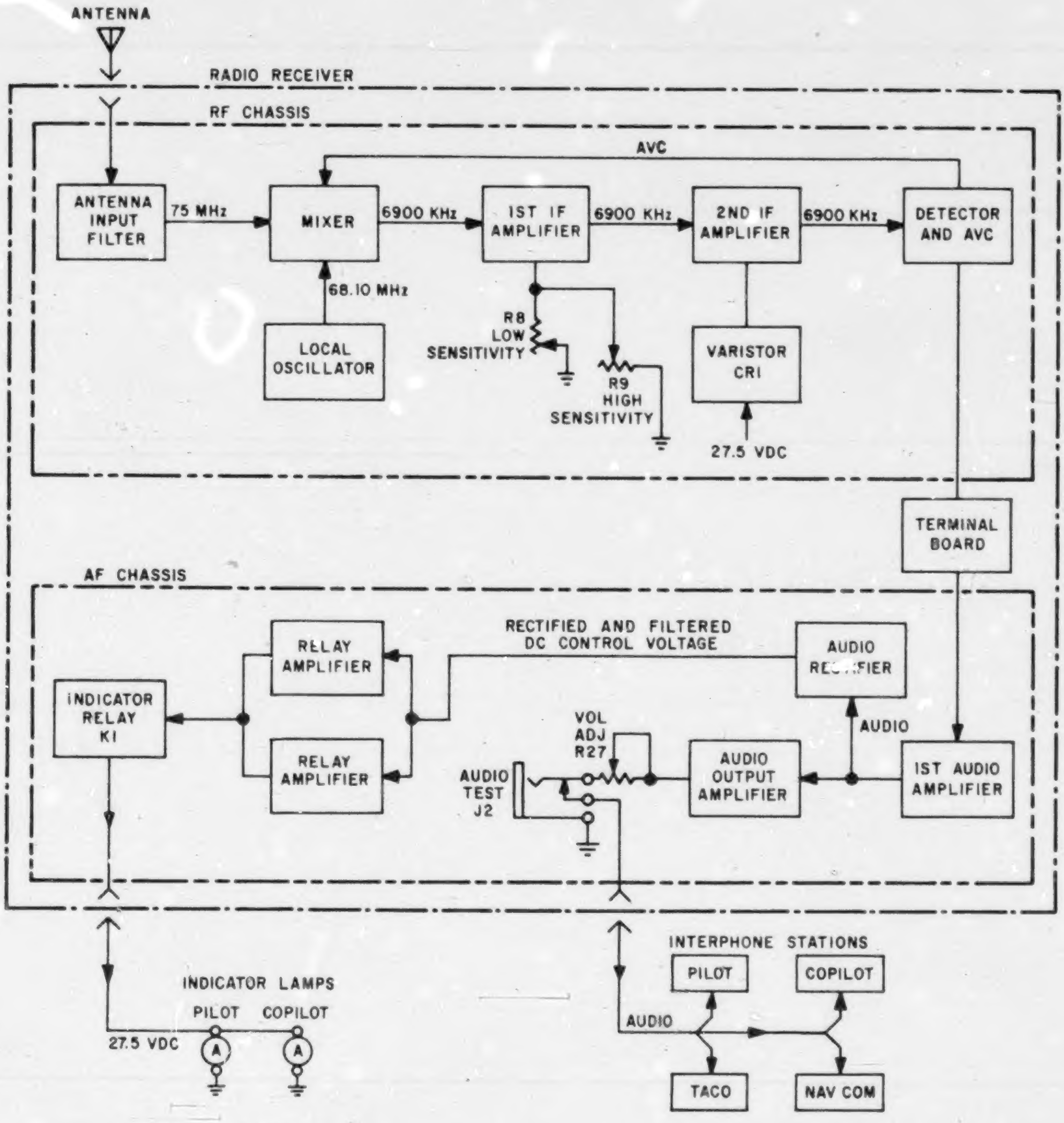
TACAN, standing for TACtical Air Navigation, is an air navigational system operating at UHF frequencies to provide the aircrew with continuous indications of bearing (azimuth) and distance (range).

The operation of TACAN range units is similar to that of IFF. The airborne unit, called the interrogator, transmits a short train of pulses which are received by the ground unit, called the transponder. After reception of the challenging pulses, the ground station sends a suitable reply to the aircraft. Upon reception of the signal by the interrogator, the elapsed time between the challenge and the reply is measured. This interval is a measure of the distance separating the aircraft and the transponder station. Bearing information is continuously transmitted by the ground station.

All airborne TACAN navigation sets are capable of two modes of operation–receive (REC) and transmit-receive (T/R). Some sets are equipped with a third mode called air-to-air (A/A). In the receive mode of operation the navigation set provides continuous bearing information from the aircraft to a selected surface beacon station. This azimuth angle is measured clockwise from magnetic north. In the transmit-receive mode the navigation set provides continuous information on the line of sight distance from the aircraft to the selected station in addition to bearing information. In both the receive and transmit-receive modes, the TACAN will provide an indentity tone, consisting of a three-letter code, which corresponds to the selected ground station. TACAN's which have the air-to-air mode will provide continuous information of the line of sight distance between two aircraft so equipped. The navigation set in each aircraft transmits interrogation signals that initiate reply signals from the corresponding navigation set. These received reply signals are then processed to produce distance information.

TACAN SYSTEM

The TACAN system consists of an airborne UHF transmitter-receiver (AN/ARN-21) and a


ANTENNA
RADIO RECEIVER
RF CHASSIS
AVC
ANTENNA INPUT FILTER
75 MHz
MIXER
6900 KHz
1ST IF AMPLIFIER
6900 KHz
2ND IF AMPLIFIER
6900 KHz
DETECTOR AND AVC
68.10 MHz
LOCAL OSCILLATOR
R8 LOW SENSITIVITY
R9 HIGH SENSITIVITY
VARISTOR CR1
27.5 VDC
TERMINAL BOARD
AF CHASSIS
RELAY AMPLIFIER
RECTIFIED AND FILTERED DC CONTROL VOLTAGE
AUDIO RECTIFIER
INDICATOR RELAY K1
AUDIO
VOL ADJ R27
RELAY AMPLIFIER
AUDIO TEST J2
AUDIO OUTPUT AMPLIFIER
1ST AUDIO AMPLIFIER
INTERPHONE STATIONS
PILOT
COPILOT
INDICATOR LAMPS
PILOT
COPILOT
27.5 VDC
A
A
AUDIO
TACO
NAV COM

AT. 329

Figure 10-11.—AN/ARN-32 marker beacon block diagram.

surface station (AN/URN-3A or AN/SRN-6A). Bearing information is accurate to within 0.25°. The maximum slant range is 195 nautical miles with an error of less than 1,000 yards. The error at close range is less than 200 yards. The system has 126 two-way operating channels in the range of 962 to 1213 MHz. Each channel uses two separate frequencies spaced 63 MHz apart. Adjacent channels are separated by 1 MHz. Each of the 126 channels is capable of providing full service without interference to over 100 aircraft. A simplified block diagram of a complete system is shown in figure 10-12.

Both the AN/ARN-21 and the AN/URN-3 contain a receiver and a pulsed transmitter. The surface station continually transmits signals consisting of randomly spaced pulse pairs, pulse-pair distance replies, and evenly spaced and coded groups of paired pulses. Due to the antenna configuration and rotation, all of these signals arriving at a given location are amplitude modulated at both 15 and 135 Hz. The surface station transmits approximately 3,600 pulse pairs per second. The main azimuth reference burst is transmitted each time the antenna passes a given azimuth (usually magnetic east) and consists of 12 pulse pairs with 30 microseconds between pairs. The antenna rotates at 15 rps (12 × 15 equals 180 pulse pairs per second). The auxiliary reference bursts are transmitted eight times during one revolution of the antenna and consist of 6 pulse pairs with 24 microseconds between pairs (8 × 15 × 6 equals 720 pulse pairs per second). This gives a total of 900 pulse pairs per second used for azimuth reference signals. The remaining 2,700 pulse pairs per second are transmitted at random. Some of these random pulse pairs are controlled by distance interrogation signals from aircraft to give distance replies.

This type of modulation is referred to as pulse-time modulation. It is a refinement of the pulse modulation technique used with radar. In pulse modulation, the transmitter is keyed or triggered; in pulse-time modulation, this triggering is encoded in some manner involving time. In this system the timing of the pulse is part of the intelligence to be conveyed, and compatible pulse-time circuitry is required to extract the intelligence from the wave. In the TACAN system the transmitter sends out a comparatively large number of pulses, most of which are meaningless. The only pulses which convey intelligence are those with a definite time relationship to each other. A receiver which does not have a compatible decoding circuit is incapable of demodulating the signal and using the information. At intervals (usually every 37.5 seconds), the random pulse pairs are replaced by pulse pairs with fixed spacing arranged to form Morse code, thus enabling the interrogating aircraft to determine the identification of the radio beacon with which it is in contact.

Whenever the surface station receives a distance interrogation pulse pair from any aircraft, it transmits a pulse pair reply (using one of the 2,700 random pulse pairs) exactly 50 microseconds after receiving the interrogating pulse pair.

TACAN ANTENNA

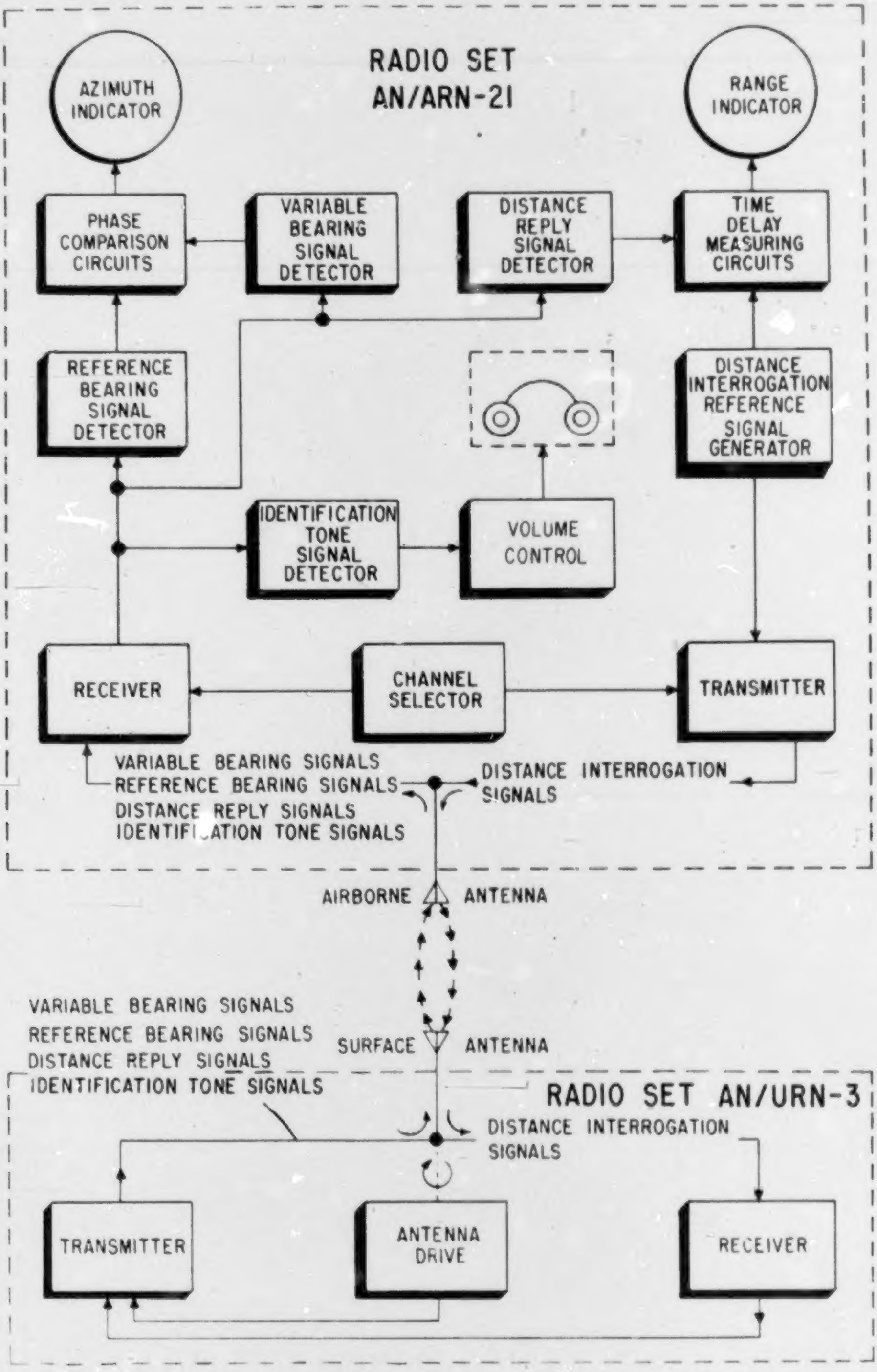
The AN/URN-3 antenna consists of a central stationary driven element with a rotating array of one main parasitic reflector element and nine auxiliary parasitic reflector elements to give an antenna pattern that is a combination of a cardioid with nine lobes superimposed on it. (See fig. 10-13.) Every time the main lobe of the antenna passes magnetic east, the AN/URN-3 transmits the main reference burst of 12 pulse pairs (30 microseconds between pairs). Every time one of the other eight auxiliary lobes passes magnetic east, the AN/URN-3 transmits an auxiliary azimuth reference burst of 6 pulse pairs (24 microseconds between pairs). Since the pattern is rotating at 15 rps, an aircraft in the position shown would receive a signal containing pulse pairs amplitude modulated at both 15 Hz and 135 Hz. (See fig. 10-14.) One is called the 15-Hz variable bearing signal, and the other is called the 135-Hz variable bearing signal.

AIR-TO-AIR TACAN

The original TACAN system was limited to an air-surface application–no provisions were made for air-to-air ranging. However, the newer concept of TACAN includes this feature and uses the AN/ARN-21D or the AN/ARN-52(V) equipment.

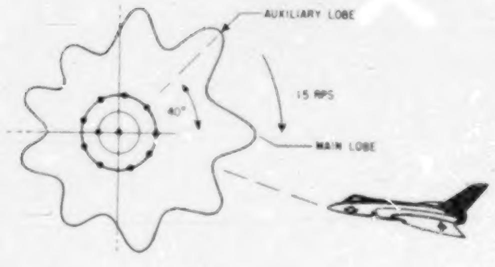
In the AN/ARN-21D, the air-to-air link functions primarily because of a modification permitting "image frequency" reception. Ranging is made possible by adding a transponding function to the airborne equipment. Both ends of the link display distance information simultaneously; therefore, the technique is called "bilateral ranging." The TACAN ground station is not involved in the air-to-air link.

The airborne sets receive on frequencies displaced 63 MHz from their transmitting frequen-


RADIO SET
AN/ARN-21
AZIMUTH INDICATOR
RANGE INDICATOR
PHASE COMPARISON CIRCUITS
VARIABLE BEARING SIGNAL DETECTOR
DISTANCE REPLY SIGNAL DETECTOR
TIME DELAY MEASURING CIRCUITS
REFERENCE BEARING SIGNAL DETECTOR
DISTANCE INTERROGATION REFERENCE SIGNAL GENERATOR
IDENTIFICATION TONE SIGNAL DETECTOR
VOLUME CONTROL
RECEIVER
CHANNEL SELECTOR
TRANSMITTER
VARIABLE BEARING SIGNALS
REFERENCE BEARING SIGNALS
DISTANCE REPLY SIGNALS
IDENTIFICATION TONE SIGNALS
DISTANCE INTERROGATION SIGNALS
AIRBORNE ANTENNA
SURFACE ANTENNA
VARIABLE BEARING SIGNALS
REFERENCE BEARING SIGNALS
DISTANCE REPLY SIGNALS
IDENTIFICATION TONE SIGNALS
RADIO SET AN/URN-3
DISTANCE INTERROGATION SIGNALS
TRANSMITTER
ANTENNA DRIVE
RECEIVER

AT. 311

Figure 10-12.—Simplified block diagram of the TACAN system.



AT.312

Figure 10-13.—Rotating antenna pattern of AN/URN-3.

cies. Considering the ground station system as normal TACAN, the air-to-air system uses the "image" frequency. This idea is illustrated in figure 10-15.

In both systems, the transmit and receive frequencies are separated by 63 MHz. However, in the normal system, reception is below transmit frequency for channels 1 through 63 and above for channels 64 through 126. For the air-to-air (A/A) system, these situations are reversed. Thus, any AN/ARN-21D set for normal operation will not respond to A/A transmissions, regardless of the channel selected. (See fig. 10-16.)

Careful study of figure 10-16(A) illustrates the following details of TACAN operation:

1. With aircraft A and the ground station set to the same channel and aircraft set on normal mode, operation is normal. Aircraft B and C are not involved.

2. With aircraft B and C set to channels separated by 63 MHz and both aircraft on air-to-air mode, bilateral ranging is performed. Aircraft A and the ground station are not involved.

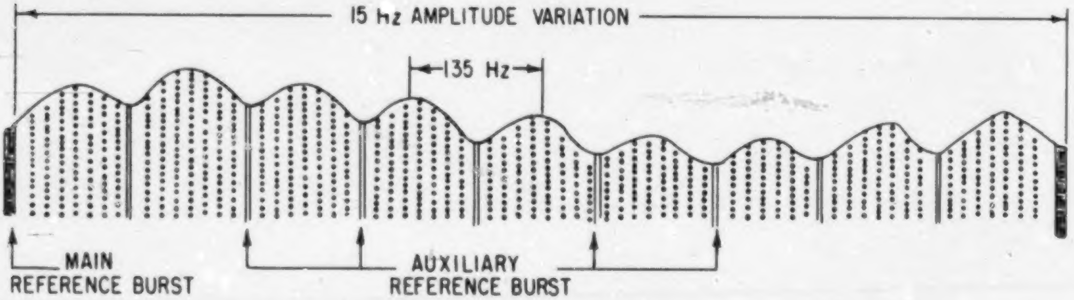
3. With aircraft A and C set to the same channel, but on different modes, they do not respond to interrogations by the other aircraft.

Figure 10-16(B) illustrates the simultaneous ranging of aircraft A and C on aircraft B, but not on each other. Aircraft B will indicate the range to one of the aircraft (which aircraft is mere chance).

In order to prevent aircraft from replying to replies, the interrogation consists of pulse pairs, while replies consist of single pulses. Replies are made only to pulse pairs.

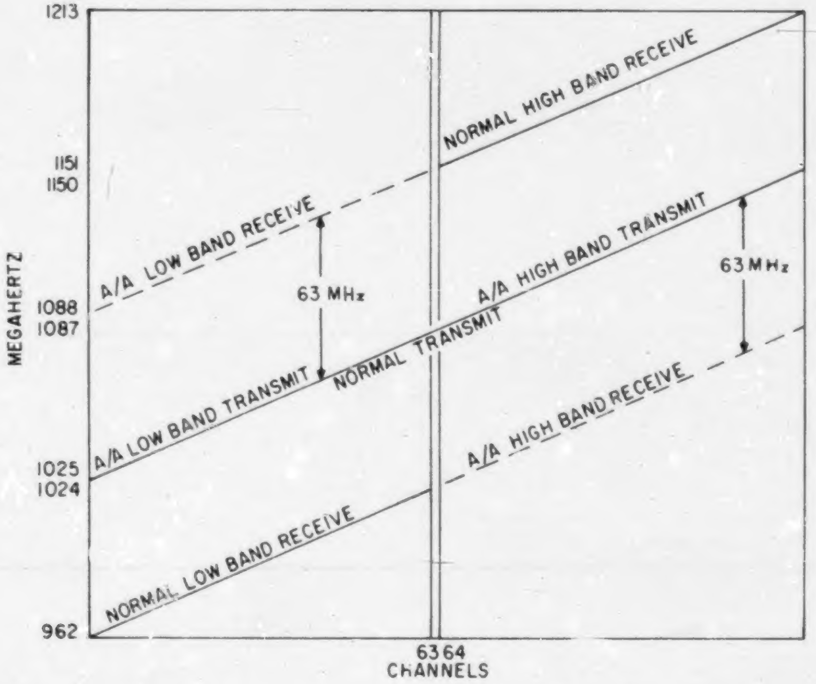
AN/ARN-21 (Series) TACAN

Radio set AN/ARN-21B is the general airborne TACAN unit used for air-to-surface operation as described previously. When modified to incorporate the air-to-air capability, the equipment is designated AN/ARN-21D and functions in either mode as selected from the control unit. In principle, operation is similar to the AN/



AT.313

Figure 10-14.—Signal received by an aircraft at 150°.



AT. 314

Figure 10-15.—TACAN frequency spectrum.

ARN-52(V) discussed in the following section. The AN/ARN-52(V) is a newer and somewhat improved airborne TACAN unit.

The AN/ARN-21 (Series) uses a 42-MHz oscillator and 42 crystals to produce the frequencies needed for the 126 channels.

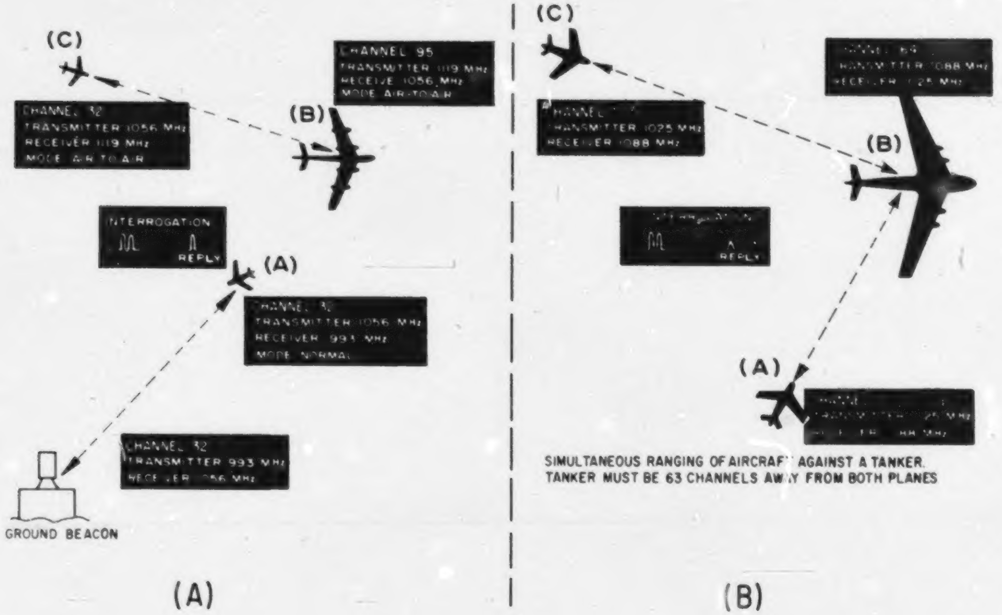
The AN/ARN-52(V)

The AN/ARN-52(V) contains additional features and improvements, even though it is slightly smaller and approximately 20 pounds lighter than the AN/ARN-21. In addition to the air-to-surface and air-to-air features, the AN/ARN-52(V) contains built-in range and bearing mechanical modules. Minimum power output has been increased to 1.5 kw, and the range readout has been increased to 300 miles. It also uses 126 crystals—one for each channel, instead of the 42-MHz oscillator and 42 crystals used in the AN/ARN-21B. In air-to-air mode, it responds to a maximum of five interrogating aircraft.

The AN/ARN-52(V) can be adapted to supply and process distance and bearing information for use in various indicators, automatic pilots, and computers. The indicators used in conjunction with this equipment include a bearing-distance-heading indicator (BDHI) such as the ID-663/ARN, a course indicator such as the ID-387, a radio bearing indicator such as the ID-250, and/or a distance indicator such as the ID-388.

The AN/ARN-52(V) operates in any of three modes. It can receive bearing and station identity information; receive range, bearing, and station identity information; or receive and transmit bilateral air-to-air ranging information.

As installed in an aircraft, the AN/ARN-52(V) uses two antennas mounted in such a manner that any "blind" spot of one antenna is covered


(C)
CHANNEL 32
TRANSMITTER 1056 MHz
RECEIVER 1119 MHz
MODE AIR TO AIR
CHANNEL 95
TRANSMITTER 1119 MHz
RECEIVE 1056 MHz
MODE AIR-TO-AIR
(B)
INTERROGATION
REPLY
(A)
CHANNEL 32
TRANSMITTER 1056 MHz
RECEIVER 993 MHz
MODE NORMAL
CHANNEL 32
TRANSMITTER 993 MHz
RECEIVER 1056 MHz
GROUND BEACON
(A)
(C)
TRANSMITTER 1025 MHz
RECEIVER 1088 MHz
TRANSMITTER 1088 MHz
RECEIVER 1025 MHz
(B)
REPLY
(A)
SIMULTANEOUS RANGING OF AIRCRAFT AGAINST A TANKER.
TANKER MUST BE 63 CHANNELS AWAY FROM BOTH PLANES
(B)

AT. 315

Figure 10-16.–TACAN air-to-air system operation.

by the other. An automatic antenna selector circuit connects the RF circuits to that antenna which provides a usable TACAN signal. In the absence of a usable signal, this circuit switches the equipment back and forth between the two antennas. When a suitable signal is received at one antenna, the equipment is locked to that antenna. Loss of a usable signal initiates a memory period to prevent loss of lock resulting from short-duration transient conditions.

The basic frequency of the selected crystal (42.7 to 47.9 MHz) goes through several stages of multiplication and amplification to produce two outputs at the transmission frequency. One signal is amplified, pulse modulated, and radiated from the antenna. The other signal is used in the crystal mixer as a local oscillator signal to produce the 63-MHz IF signal.

For further details concerning TACAN equipments, refer to the applicable technical manuals.

BENCH TEST AND ALINEMENT

The majority of aircraft TACAN equipment is tested and alined with the use of Radio Test Set AN/ARM-22A. This test set provides air-to-air (A/A) testing capabilities and simulates navigational signals that are normally provided by the Radio Set AN/URN-3 (or other TACAN station radio transmitter), a part of the TACAN system.

The AN/ARM-22A can simulate fixed or variable ranges from 0 to 198 miles, all bearings from 0° to 360°, and tone for operation of the identity circuits of the aircraft TACAN equipment. In addition, the test set can transmit these simulated signals to equipment being tested on any one of 126 preselected channels.

The radio test set may be mounted on a mobile dolly to facilitate flight line testing of airborne components.

When the radio test set is used in conjunction with Test Set Indicator AN/ARM-31, the capabilities of the equipment are increased. The simulated information sent to and then processed by the equipment being tested is displayed on the test set indicator in the AN/ARM-31. This enables the operator to test individual components of the aircraft equipment.

Another piece of support equipment used in checking a TACAN system is the AN/URM-101. It is a lightweight, easy-to-use unit developed to provide both a visual and an aural indication of the operational status of the radio set under test. This portable, self-contained unit simulates a TACAN beacon, and receives from and transmits to a TACAN set either by radiation from an antenna or by direct connection with coaxial cable. The AN/URM-101 will operate with up to four individual units simultaneously.

LORAN

The word LORAN is formed from the words LOng RAnge Navigation. It is a navigational system developed primarily to provide a means for making geographical fixes by the use of long range radio signals. The system is a valuable aid to navigation, since loran fixes can be made quickly and accurately both by night and day. It is reliable for both air and surface navigation under most weather conditions. Loran signals can often be received even during storms, except those involving severe electrical disturbances. The principal value of loran lies in its capability of continued operation during conditions which make celestial navigation difficult or impossible. Such conditions include any situation in which the stars are not visible.

PRINCIPLES OF LORAN

In principle, loran differs from radar in that the airborne unit simply receives radio pulses broadcast from ground stations, and no reception of echo signals is involved. The basic loran measurement is that of time difference of

When the radio test set is used in conjunction

arriving signals with no regard to the direction from which they arrive; hence, the complicated directional antennas used in radar equipment are not necessary. Despite these differences, however, loran is closely related to radar since it uses pulse type equipment, and it employs radar techniques of time measurement. Also, visual displays of the signals received are made on cathode-ray tubes used as indicators.

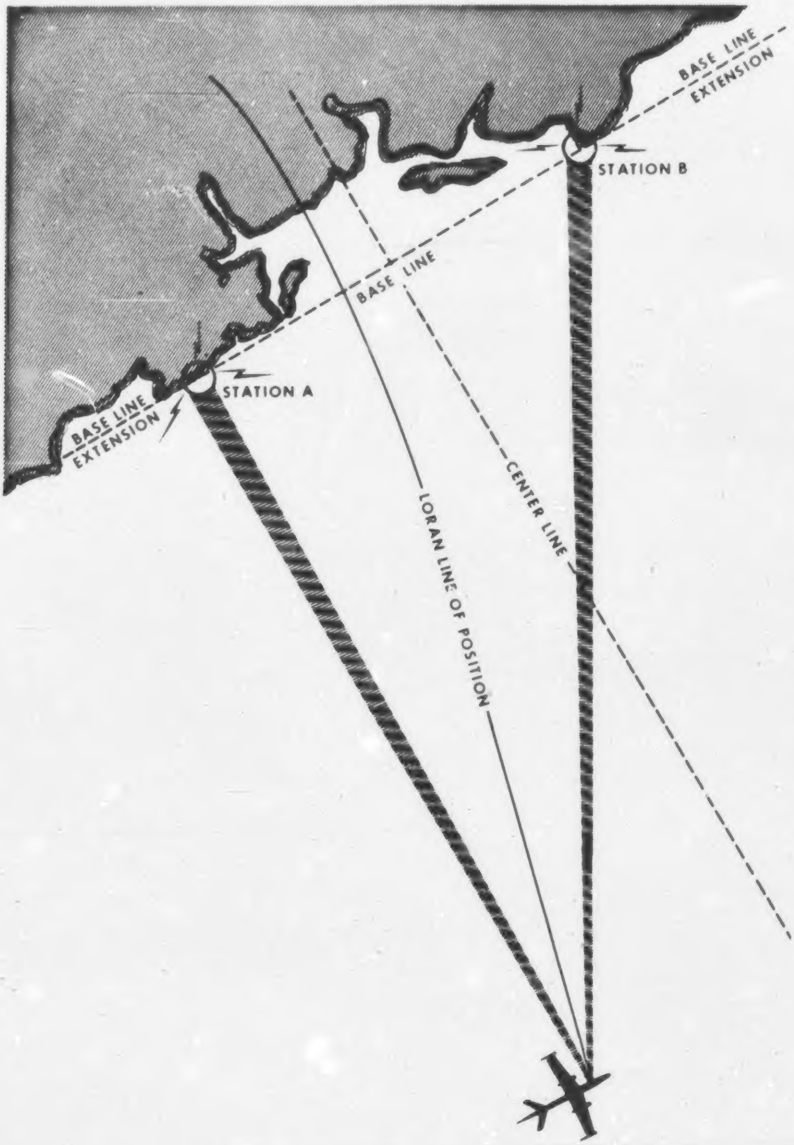
The basic principle of the system is illustrated in figure 10-17. Two stations are necessary to establish a loran line of position. The master station A emits a continuous series of uniformly spaced pulses at a stable pulse recurrence rate. The slave station B sends out a similar series of pulses which are synchronized with the master pulses. The master and slave stations are usually 200 to 400 miles apart. The line joining the two stations is called the baseline, and its perpendicular bisector is called the centerline. The baseline extension is a straight line drawn beyond either station as a continuation of the baseline.

Assume that the two stations are sending out pulses simultaneously; then at any point along the centerline, the two signals arrive at the same instant (since all points of the line are equidistant from the two transmitters). If an observer is located nearer station A than station B, the A pulse arrives at his position first, followed (after a measurable time interval) by the corresponding B pulse. By moving to different positions located in the same vicinity, the observer could record the time interval (difference in arrival time of the A and B pulses) corresponding to each position. If several positions having the same time interval were joined by a smooth curve, the curve thus traced would be a line of position for station pair A and B.

The difference in the time of arrival of the pulses corresponds to the difference in distance from the stations, and can be accurately calculated and plotted on a chart. Selected line of position curves may be drawn by connecting points of equal computed time or distance values. Each curve so constructed has the shape of a hyperbola, which is the mathematical name for a curve consisting of points whose difference in distance from two fixed points (in this case, A and B) remains constant. Thus, loran is called a hyperbolic system of navigation.

A large number of lines of position are drawn for each pair of transmitters as shown in figure 10-18. Each line is labeled with a number indicating the time interval in microseconds between the arrival of the corresponding loran pulses.

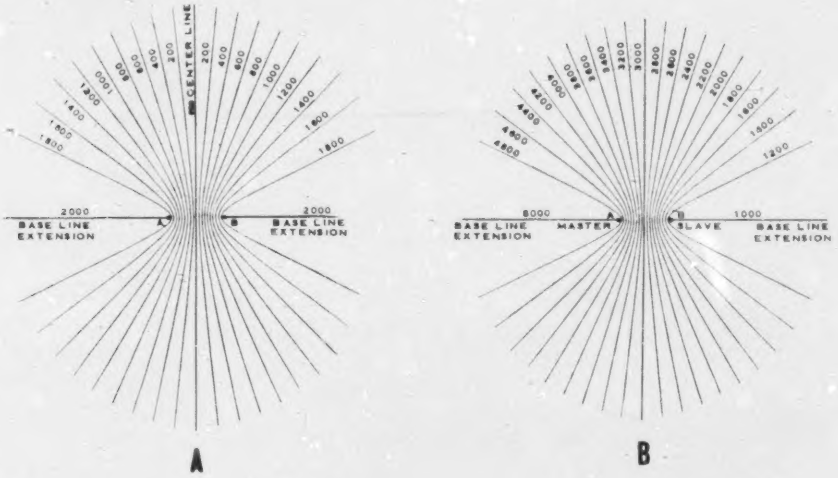
In (A) of figure 10-18, zero time difference


BASE LINE
EXTENSION
STATION B
BASE LINE
STATION A
BASE LINE
EXTENSION
LORAN LINE OF POSITION
CENTER LINE

AT. 316

Figure 10-17.–The principle of loran.

exists along the centerline, while maximum time difference exists along the baseline extensions. Lines with equal time difference may be noted on each side of the centerline, since there is no way to determine which pulse is received from which station. In actual practice, however, the signals are not emitted simultaneously. The slave station pulse is delayed so that, at any point, the master station pulse is received before the corresponding slave pulse. As a result, each curve of



AT. 317

Figure 10-18.—Lines of position. (A) No time delay; (B) 3,000-microsecond delay.

the family has a discrete time interval value as indicated in (B).

The delay of the slave pulse includes several increments. The master station transmits a pulse to initiate the sequence of events. An interval of time elapses during which the signal reaches the slave station. The slave station receives the impulses and waits an initial period of time (equal to one-half the pulse recurrence interval) plus an additional period of time (called the coding delay). It then emits a pulse. The sum of the travel time, half the recurrence interval, and the coding delay is called the absolute delay. As a result of the delay, the master pulse always precedes the slave signal at any point of reception. The difference in arrival time is maximum along the baseline extension beyond the master station and minimum on the baseline extension beyond the slave station.

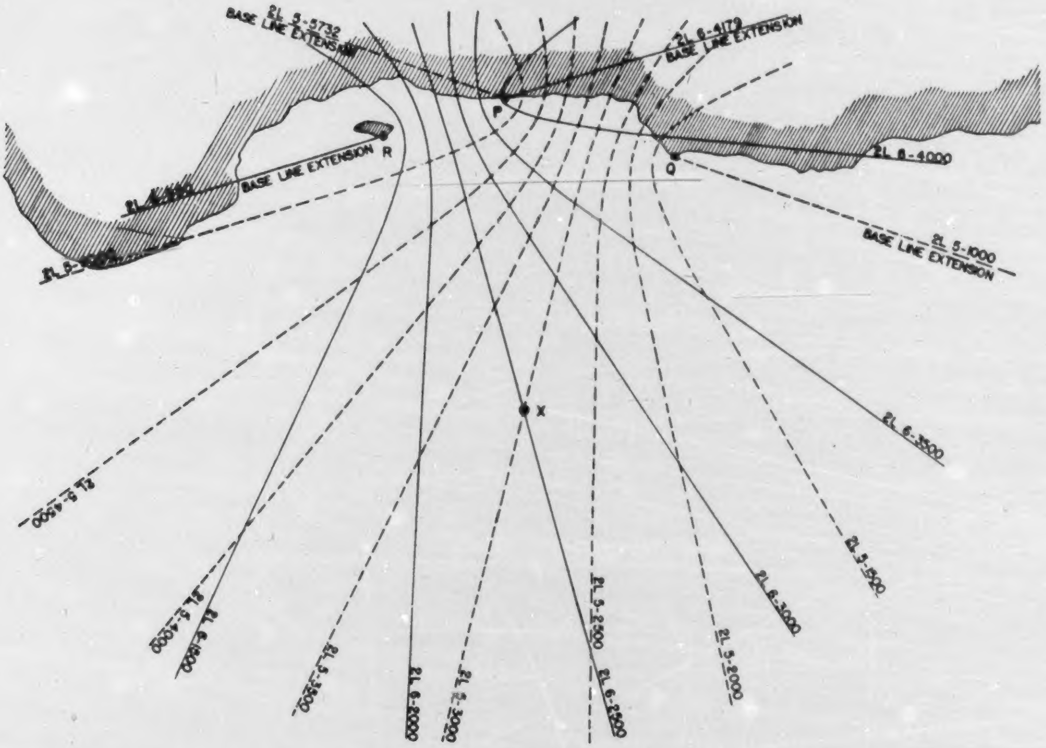
LORAN NAVIGATION

The loran navigation network is designed to cover a vast ocean area. This fact, coupled with the long distance usage, requires a fairly large number of stations. However, loran stations operate in a crowded portion of the radio spectrum; therefore, only a few specific frequencies are available. At the present time, only 3 channels are used, but as many as 24 station pairs may be operated on each. This is made possible by using a different pulse recurrence rate for each station pair on any channel. The equipment can thus distinguish between various pulse pairs and measure the time interval for any selected pair. Other pulse pairs are not synchronized with the CRT sweep, and therefore drift across the screen.

In order to determine a position by loran, it is necessary to obtain intersecting lines of position from two or more station pairs, then refer to a special loran chart to locate the position of that intersection.

The U.S. Navy Hydrographic Office publishes loran charts (which are standard Mercator charts with loran lines of position superimposed). The use of the chart in obtaining a "fix" is illustrated in figure 10-19.

A loran chart shows the lines of position of one station pair crossing those of another. In


2L 5-5732
BASE LINE EXTENSION
2L 6-4179
BASE LINE EXTENSION
P
R
BASE LINE EXTENSION
Q
2L 6-4000
2L 5-1000
BASE LINE EXTENSION
X
2L 5-4500
2L 6-3500
2L 5-1500
2L 6-3000
2L 5-4000
2L 6-1500
2L 5-3500
2L 6-2000
2L 5-3000
2L 5-2500
2L 6-2500
2L 5-2000

AT. 318

Figure 10-19.–Obtaining a loran fix.

many installations, the two pairs consist of a single master station operating in conjunction with two slave stations. This is called double-pulsed transmission and is the type represented in figure 10-19. The common master station emits two sets of pulses. Each set is synchronized with one of the adjacent slave stations. In the figure, the master station is labeled P, and the slave stations are labeled R and Q. The combination P-R operates with a pulse recurrence rate that is different from the combination P-Q. Two families of lines are available, and the fix is made by taking measurements on both pairs, locating the observer at point X.

When loran fixes are made, the general location is usually known. The navigator consults the loran chart for that particular area and selects a station pair by setting the receiver controls according to the symbols given on the chart. The principal receiver settings are for channel frequency, basic pulse recurrence rate (high or low), and specific pulse recurrence rate. These required settings are indicated by the letter-number groups noted on each line of position. The last part of the group is the time difference (in microseconds) for that line of position.

LORAN AIRBORNE EQUIPMENT AN/APN-70

Receiving Set AN/APN-70 is an airborne navigational aid used to receive and interpret loran signals. It is installed in patrol, transport, and other long range aircraft. It is designed to operate over the standard medium frequency loran band from 1.7 to 2 MHz, and on the two low frequency channels from 90 to 110 kHz and 170 to 190 kHz.

The AN/APN-70 receiver uses the same antenna used by other electronic devices (such as communication receivers) in the same aircraft. An antenna coupler serves to isolate the loran equipment and to prevent interaction with the other electronic systems which share the common antenna. In addition to isolation of the receiver, the coupler unit also provides a means of matching the unit to the characteristics of different antennas, for amplifying signals to which the set is tuned, and for attenuating unwanted reception. Four stages of amplification are contained in the antenna coupler together with the associated impedance-matching and attenuation circuits. One stage is used with the loran system.

Principles of Operation

The receiver gives a direct reading in microseconds of the indicated time difference between the arrival of the master and slave pulses received from the loran transmitting stations in use. To measure this time difference, a fixed reference (master pedestal) and a variable reference (slave pedestal) must be used on the CRT. Variable-delay circuits, which are mechanically connected to a crank on the front panel, are incorporated in the equipment to give a variable pedestal on the lower trace. The indicated time difference is obtained by placing the master pulse on the leading edge of the fixed pedestal of the upper trace and positioning the leading edge of the variable pedestal of the lower trace under the slave pulse. The elapsed time can then be read on the front panel from counters connected to the crank.

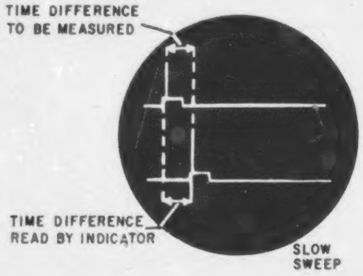
The receiver contains two delay systems so one reading for a standard loran station pair can be retained while the second value from another station pair is being taken. If one delay system fails, the equipment is still usable, since the two time difference readings required for a fix can be obtained from the remaining operating delay system.

The AN/APN-70 equipment provides for simultaneous reception of two low frequency loran stations. In this type of operation, the two time difference readings corresponding to lines of position appear simultaneously on the revolution counter dials. The simultaneous readings are based on triad operations of the transmitters. The loran triad consists of a master station which controls two slaves. The master transmitter is pulsed at twice the recurrence rate of the slaves while the slaves emit pulses at the same recurrence rate. One pulse from each slave is sent during each recurrence period, L, and the master pulses occur at intervals of L/2.

The master pulses are called X and Z, and the slave pulses are known as Y and W. During reception of signals from triads, all four pulses appear on the indicator in the sequence X-Y-Z-W. In order that the pulses can be identified readily on the screen, the X pulse is followed closely by a "ghost," resulting in a double vertical deflection.

The two readings given by the revolution counters are plotted on loran charts and enable the operator to determine his location.

The electron beam in the indicator tube traces two time baselines, one above the other, as indicated in figure 10-20. Moving from left to right, the beam slowly traces the upper line in a period of time equal to one-half the pulse recurrence interval. It quickly retraces, jumping to the left and below. It then traces the lower baseline in


TIME DIFFERENCE TO BE MEASURED
TIME DIFFERENCE READ BY INDICATOR
SLOW SWEEP

AT. 319

Figure 10-20.—Time difference measured on a loran indicator.

one-half the recurrence interval before rapidly returning to the start of another top line.

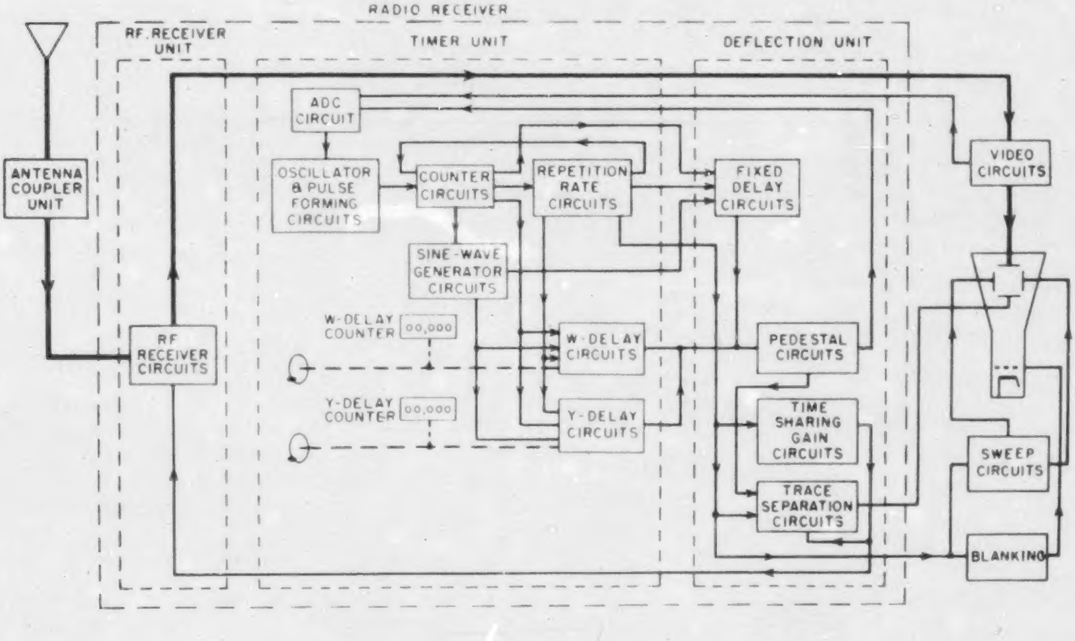
The master station pulse is superimposed on the upper baseline, and the slave pulse appears on the lower. When the receiver is correctly adjusted, the station pulses are displayed above pedestals (rectangular deflections) in the time baselines. The pedestals indicate portions of the display which can be expanded and examined in greater detail for accurate measurement. The time difference to be measured is represented by the horizontal distance between the master pulse on the left and the slave pulse below it to the right. This method of measuring the time difference automatically cancels the fixed delay of one-half the recurrence rate by which the slave pulse was retarded during transmission.

Theory of Operation

The APN-70 receiver assembly is composed of three major units: the RF receiver, the timer, and the deflection units. These sections are shown in block diagram form in figure 10-21, which also includes the components of the loran indicator.

RF RECEIVER UNIT.—This portion of the loran receiver is a superheterodyne system, which contains an RF amplifier, a converter, two IF amplifiers, a detector, and a video amplifier. Loran signals are received from the antenna coupler by the RF amplifier, a tuned-grid, tuned-plate circuit. The output of the amplifier is applied to the converter stage.

One section of the converter stage is used as a crystal oscillator circuit that produces mixing voltages. The IF output of the converter is amplified in the two IF amplifiers and fed to the detector. The resulting video pulses pass through one stage of amplification and are coupled through a cathode follower and the video section of the indicator to the vertical deflection system of the cathode-ray tube.


RADIO RECEIVER
RF RECEIVER UNIT
TIMER UNIT
DEFLECTION UNIT
ANTENNA COUPLER UNIT
RF RECEIVER CIRCUITS
ADC CIRCUIT
OSCILLATOR & PULSE FORMING CIRCUITS
COUNTER CIRCUITS
REPETITION RATE CIRCUITS
FIXED DELAY CIRCUITS
SINE-WAVE GENERATOR CIRCUITS
W-DELAY COUNTER
00,000
W-DELAY CIRCUITS
Y-DELAY COUNTER
00,000
Y-DELAY CIRCUITS
PEDESTAL CIRCUITS
TIME SHARING GAIN CIRCUITS
TRACE SEPARATION CIRCUITS
VIDEO CIRCUITS
SWEEP CIRCUITS
BLANKING

AT. 320

Figure 10-21.—Receiver, AN/APN-70, block diagram.

TIMER UNIT. This unit generates a series of pulses serving as the time base of the equipment and produces the variable-delay intervals used to measure the time differences of the loran pulses. Also, to insure that the receiving set and the transmitter system are operating at the same recurrence rate, the timer contains circuits for synchronizing the two.

The timing standard in the receiver is an 80-kHz crystal oscillator from which is derived (either directly or indirectly) the time bases for the timer, delay, and deflection circuits. The oscillator is synchronized with the time base of the loran transmitter by the action of the automatic drift control circuits. The oscillator can be changed in frequency over a narrow range by a reactance tube whose d-c input grid voltage assumes a value corresponding to the degree of synchronism of the receiver circuits with the incoming loran pulses. The grid voltage of the reactance tube is produced by a discriminator tube which compares the repetition rate of the incoming master and slave pulses with the master and delay pulse pedestals from the receiver-indicator. (The master and delay pulses have a pulse rate set by the timer.) Any variation in the two rates produces a d-c bias on the control grid of the reactance tube which, in turn, corrects the oscillator frequency and the resulting pulse rate derived from it. Thus, automatic drift control is established.

The sine-wave output of the crystal oscillator is shaped to produce a sharp negative driving pulse which is applied to the counter circuits. The electronic counter contains 12 identical multivibrators and 10 identical interstage amplifiers. Each counter stage is a binary counter (divides the input pulse rate by 2). The first 11 of these stages, together with 10 interstage amplifiers, are used to obtain the repetition rate. The 12th stage is driven by the output of the repetition rate circuits to obtain a square wave which is equal to the recurrence rate of the loran transmitting stations selected.

The first multivibrator of the counting series is triggered by 80-kHz pulses derived from the pulse forming circuits. The output of the first stage is fed to the grid of the first interstage amplifier tube which drives the second multivibrator. This sequence is repeated throughout the first 11 stages so that the overall division ratio is 2,048 to 1; hence, the counter chain gives one output pulse for every 2,048 pulses fed into it when all 11 counters are used.

The repetition rate circuits accept the output of the counter section and produce the reset pulses which determine the time at which the counter stages reach the count selected by the position of the recurrence rate switch. At that time a pulse is generated to reset the counter chain for the next cycle and to drive the 12th stage. The position of the recurrence rate switch may be set for any one of the 24 loran repetition rates. In addition, the repetition rate circuits supply trigger pulses to the fixed-delay circuits, the time-sharing gain circuits, and to the sweep circuits in the indicator unit on position 1 of the function switch.

The W- and Y-delay indicating systems consist of dials, switches, gear trains, gating tubes, wave shapers, pulse formers, and thyratrons. These systems are connected to stages 3 through 11 of the binary counter chain and to the 12th stage. Each delay system produces one output pulse during each L period. The occurrence of this output can be varied uniformly and continuously (after the second reset) to start the succeeding loran cycle by means of a handcrank. Two dials indicate the microseconds of delay produced at the thyratron of each system. The W and Y systems are identical in construction and operation except that their outputs appear in successive L/2 periods for operation with low frequency loran signals (dual presentation). With high frequency (single presentation) loran reception, only one delay system operates, as determined by the setting of the W-Y switch.

DEFLECTION UNIT. In addition to the low voltage power supply, the deflection chassis contains circuits that receive signals from the timer unit. These signals are used to synchronize and trigger waveforms that perform the following functions:

1. Generate three independent bias voltages for the three time-sharing gain circuits.

2. Generate waveforms to drive the sweep generator in positions 2, 3, 4, and 5 of the function switch.

3. Generate trace-separation waveforms when required by the function selected at the control panel.

In single presentation, the time-sharing gain controls enable the operator to adjust the receiver gain to an independent level on each trace appearing on the indicator screen. Either the W- or the Y-delay system may be independently selected by a control switch. In dual presentation, the delay reading and the gain setting of one pair of loran stations may remain on one counter dial and gain control knob while the operator is matching a second pair of loran pulses using the second delay system. The output of the time-sharing gain circuits supplies bias to the RF and IF stages of the RF receiver unit.

The trace-separation circuits are connected to the lower vertical deflection plate of the cathode-ray tube. The fixed-delay circuits provide a 1,625-microsecond delay for the trigger, governing the appearance of the master pedestal. For dual presentation, one trigger signal for every L/2 interval is provided; in single presentation, only one trigger signal for every alternate L/2 is required.

The pedestal circuits receive pulses from the fixed-delay and variable-delay circuits and generate waveforms to produce the master and slave pedestals. The output waveforms are supplied by a cathode-coupled, one-shot multivibrator which provides a pedestal of approximately 400 microseconds in positions 3 and 5 of the function switch in single and dual operation. The pedestal is 1,200 microseconds long in position 1, 2, and 4 of the function switch in single operation, or 1,750 microseconds long in dual operation. In position 1 of the function switch, the multivibrator generates the pedestals seen on the traces on the indicator tube. In other positions of the switch, the pedestals are used to generate the traces, and only the video signals present during the portion of the pedestal covered by the trace are shown on the indicator tube.

LORAN INDICATOR.—As shown in figure 10-21, the loran indicator contains the sweep circuits for developing the horizontal deflection voltages, the cathode-ray tube blanking circuits, the video circuits, and the cathode-ray tube. In addition, the assembly contains two high voltage rectifiers which supply d-c potentials for the CRT.

The sweep and blanking circuits are triggered by the reset pulses from the repetition rate circuits on function 1 and by the pedestal generator circuits on functions 2, 3, 4, and 5. A horizontal sweep generator supplies a sawtooth voltage waveform that is applied to the left horizontal deflection plate of the CRT. A portion of the output is also fed to a phase inverter stage to give an output wave 180° out of phase with the sweep generator output and which is applied to the right deflection plate, thus providing a push-pull horizontal deflection.

The blanking circuit extinguishes the electron beam in the indicator tube during retrace intervals in which the grid in the indicator tube is driven highly negative with respect to the cathode. A d-c restorer diode clamps positive swings of the CRT grid to the voltage set by the brilliance control and establishes the level about which blanking takes place. An RC combination in the blanking circuit insures that the traces seen on the screen of the indicator tube are delayed until after the start of the sweep to remove irregularities in the initial parts of the sweep cycle.

Video signals derived from the RF receiver unit are amplified in the video circuits and are applied to the upper vertical deflection plate of the CRT.

The d-c voltages needed for operation of the CRT are supplied by low voltage regulator power supplies in the receiver unit and by the two high voltage rectifiers in the indicator assembly. One high voltage rectifier produces a d-c potential of 1,300 volts, positive with respect to ground, which is applied to the indicator tube through a cap connection. The other high voltage supply develops 1,300 volts, negative with respect to ground, and is applied to the cathode of the tube.

AUTOMATIC RADIO DIRECTION FINDER

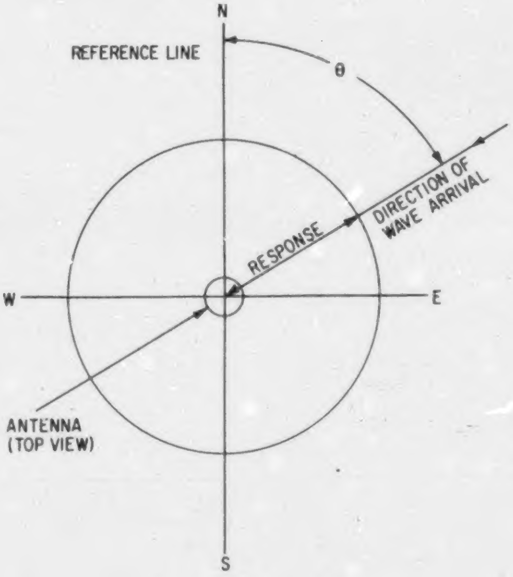
Automatic direction finders are radio receivers equippped with directional antennas which are used to determine the direction from which signals are received. Most units of this class provide facilities for manual operation in addition to automatic direction finding (ADF). The automatic mode involves the use of motor-driven antennas which are positioned by means of closed-loop control circuits.

Before the development of radar and loran, radio direction finding was one of the principal means for determining the position of aircraft in bad weather. When an aircraft is within reception range of a radio station, the ADF equipment provides a means of fixing the position with fair accuracy. In addition to its usefulness as a navigational aid, the automatic direction finder is also employed as one of the basic devices of electronic countermeasure systems.

BASIC PRINCIPLES

When a conductor is cut by magnetic lines of force, or lines of flux, a voltage is induced in the conductor. In order to cut lines of flux, the conductor must be perpendicular or must have a component that is perpendicular to the lines of flux; and the relative motion between flux and conductor must have a component in a direction that is perpendicular to both the lines of flux and the conductor.

A vertically polarized wave has a vertical electric (E) field and a horizontal magnetic (H) field; therefore, the wave induces voltage in vertical conductors only. A vertical wire, or monopole, is the simplest type of antenna. When a vertically polarized radio wave induces voltage in a monopole, the induced voltage is in phase with the incident wave and is the same for all horizontal angles of incidence. (See fig. 10-22.) This similarity of response pattern, in all directions simultaneously, suggests the name omnidirectional (omni means "all") for this type of antenna.



AT. 321

Figure 10-22.—Polar response of a monopole (sense) antenna.

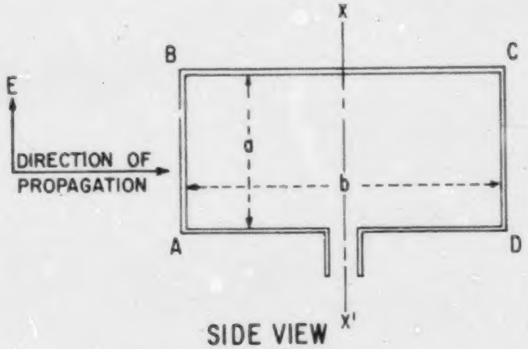
Loop and Sense Antenna

The response of a loop antenna is different from that of a vertical monopole (called a sense antenna in this discussion). A rectangular single-turn loop with dimensions that are small compared to the wavelength of an incident radiation field is shown in figure 10-23. As the loop is rotated about the axis XX', the angle θ (between the plane of the loop and the direction of propagation of the wave) is changed.

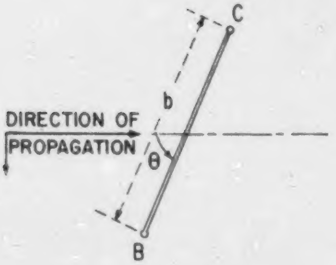
If the loop is placed in a radiation field like the one shown in figure 10-23, the H vectors of the field cut the sides AB and CD at slightly different times because the wave travels at a finite speed. At any instant, therefore, the voltage induced in arm AB is slightly different from the voltage induced in arm CD. (The arms BC and AD are not affected by the H lines of a wave polarized at right angles to them, and do not contribute to the induced voltage in the loop because the horizontal members are parallel to the H lines.)

If the loop is turned so that its face is perpendicular to the direction of arrival of the wave—that is, $\theta = 90°$, the sides AB and CD are cut by the H vector at the same instant. The voltages induced in arms AB and CD are then the same magnitude and phase and neutralize each other, so that no current flows in the antenna loop.

Since the magnetic field of the radio wave alternates at the frequency of the wave, the instantaneous flux density at any point along



SIDE VIEW
(A)



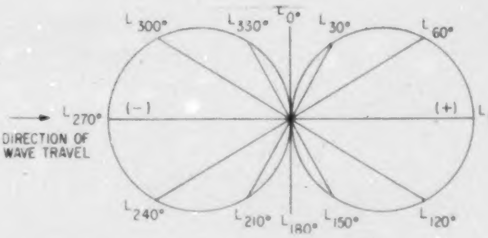
TOP VIEW
(B)

AT. 322

Figure 10-23.—Loop antenna in a radiation field.

the path of arrival varies sinusoidally. Thus the voltage induced into arms AB and CD are sinusoidal voltages with a phase difference θ. The total loop voltage is the sinusoidal voltage which represents the integration of the sums of all the instantaneous voltages induced into the two arms. It may be shown mathematically that this resultant voltage is proportional to the cosine of θ.

The pattern of the response is similar to the figure-of-eight. (See fig. 10-24.) It is by using the response as shown in this figure that all medium frequency direction-finding equipments obtain bearings.



AT. 323

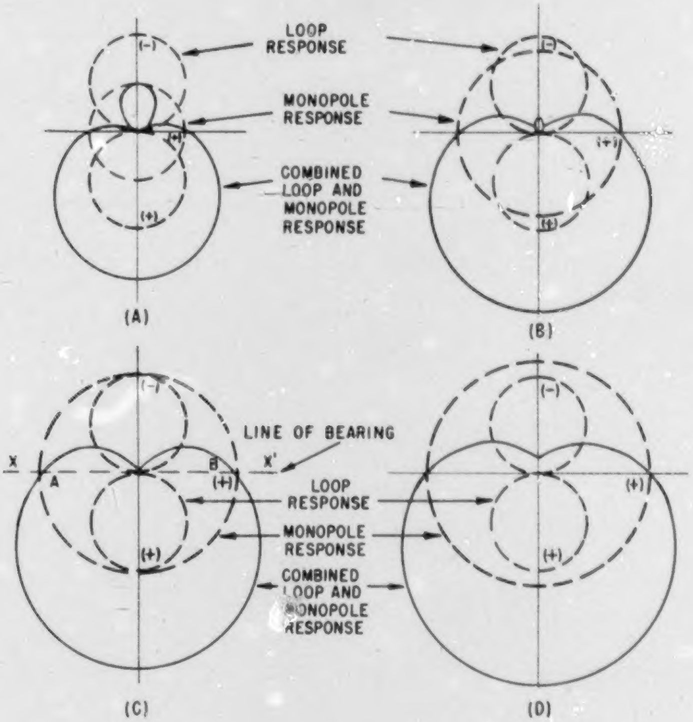
Figure 10-24.—Polar response of a loop antenna.

The directional characteristic of the loop antenna is called a cosine, or figure-of-eight pattern. When the loop is oriented so that the received signal is a maximum, a small change in orientation produces a small change in signal. However, when the loop is at a null position, a small change in orientation of the loop produces a large change in output voltage. Furthermore, there is a reversal in phase of the signal as the loop passes through a null point. For these reasons, the null points rather than the maximum-response points are used in radio direction finding to obtain a line bearing or line of arrival of a radio wave.

As there are two null positions 180° apart, the loop can give a line of bearing (the actual bearing or its reciprocal) but cannot determine the absolute direction of the transmitter from the direction finder. The determination of absolute direction, or sense, is obtained by adding the output of a vertical sense antenna to that of the loop antenna. When the two antennas are properly connected, the combined response is not ambiguous.

Signal Comparison

The figure-of-eight pattern of a loop has two null positions for one incident radio wave (fig. 10-24). If the outputs of a loop and a sense antenna are combined in phase, the response of the two antennas is the algebraic sum of their individual diagrams. In order to produce a given response, the magnitude of the individual signals must be considered. Refer to figure 10-25 for the following discussion.



AT. 324

Figure 10-25.—Response of the combined sense and loop antenna.

This figure illustrates four possible responses caused by differences in the relative amplitudes of the sense and loop outputs. The desired response shown in (C) has one sharp null.

The output of the vertical sense antenna is independent of the horizontal direction of arrival of the wave, so it may be considered to have positive polarity. Because the phase of the loop voltage changes as the loop passes through a null, one-half of the figure-of-eight pattern may be said to have positive polarity and the other half to have negative polarity. The addition of the loop and sense curves gives the responses shown. The shape of the resultant curve is called a cardioid because of its similarity to a heart.

The output of the sense antenna is in phase with the radio wave. The output of the loop antenna, however, is 90° out of phase with the radio wave. This means that the loop output voltage is a maximum when the sense output is zero and vice versa: The cardioid pattern (which depends on the outputs being in phase) cannot be obtained unless the phase of either the loop or the sense antenna signal is changed by 90°.

The cardioid pattern produced by the combined loop and sense antenna can also be produced by the rhombic antenna. This type is used without a sense element.

DIRECTION FINDER SET AN/ARD-13

Direction Finder Set AN/ARD-13 is a low frequency radio navigation device that operates in the frequency range between 90 kHz to 1800 kHz. It is capable of receiving both AM and CW transmission within its operating range.

The direction finder has three modes of operation which are selected remotely at the control unit. In the ANT mode, the RF input to the receiver is from the sense antenna; the direction finder operates as a nondirectional low frequency receiver. The RF input in the LOOP mode is from the loop antenna. The LOOP mode may be used for manual direction finding by rotating the loop for an audio output null or a tuning meter null. (A 180° ambiguity in direction is possible in the LOOP mode since the loop antenna pattern has two nulls 180° apart.) The direction from which signals are best received can be chosen manually from the control box by positioning the loop. In the ADF mode, the receiver combines signals from both the sense and loop antennas to determine whether the loop is pointed to the left or to the right of the signal source. The receiver commands clockwise rotation of the loop if the loop axis is pointed to the left of the signal source. Counterclockwise rotation is commanded if the loop axis is to the right of the signal source. Rotation ceases when the loop axis is pointed directly at the signal source.

The position of the loop is continuously transmitted to the bearing indicator. The bearing indicator reads the bearing to the station in the ADF mode, because the loop is kept pointed directly at the station. The bearing indicator combines the bearing information from the direction finder with navigation data received from other equipment. Audio signals in all three modes are supplied to the intercommunication system in the aircraft. The audio level to the ICS is varied manually from the control box. Reference to figure 10-26 should be made at frequent intervals throughout the remainder of this discussion.

Theory of Operation

ANT (ANTENNA) MODE.–Radiofrequency signals from the sense antenna are coupled to the RF amplifier through the impedance-matching network in the sense antenna couplet. The only signal input to the RF amplifier in the ANT mode comes from the sense antenna; the loop amplifier and the balanced modulator are disabled. The oscillator and mixer convert the output of the RF amplifier to 455.7 Hz, the intermediate frequency of the receiver. The oscillator is tuned from the control box by the tuning servo. One of two mechanical filters passes the desired signal and attenuates the undesired signals. The broad filter provides selectivity of 3.1 kHz, and the sharp filter provides receiver selectivity of 1.5 kHz. The narrow band output of the mechanical filters is amplified by the IF amplifier and is applied to the detectors. The output of one detector is used as the automatic volume control (AVC) signal to limit the gain of the RF and IF amplifiers. The AVC signal is also applied to the tuning meter. The output of the other detector is applied to the audio amplifier. The audio gain control is bypassed in ANT mode and manual control of receiver gain is with the RF gain control. The audio amplifier increases the output of the detector to the level required by the ICS in the aircraft.

LOOP MODE.–Rotation of the loop antenna is controlled by the LOOP switch on the control box. The LOOP switch applies either of two phases of 400-Hz a.c. from the receiver to the loop rotating motor in the loop antenna. In practice, the operator uses the LOOP switch to drive the loop antenna to the position of minimum reception of the received signal. This position of minimum reception, which occurs when the loop antenna is pointed directly at the signal source, is called the null position. The angle of the transmitting station, with respect to aircraft heading, can then be read accurately on the bearing indicator. The RF output of the loop antenna is applied to the balanced modulator through the loop amplifier. The balanced modulator is unbalanced during loop operation and couples the output of the loop amplifier to the RF amplifier. Signals from the balanced modulator are the only input to the RF amplifier in the loop mode. The input to the RF amplifier is the same as in the antenna mode operation.

ADF MODE.–The RF output of the loop antenna has either of two phases relative to signals from the sense antenna. Phase A, as shown, occurs when the loop antenna is to the right of the null position. Phase B occurs when the loop is to the left of the null. The loop

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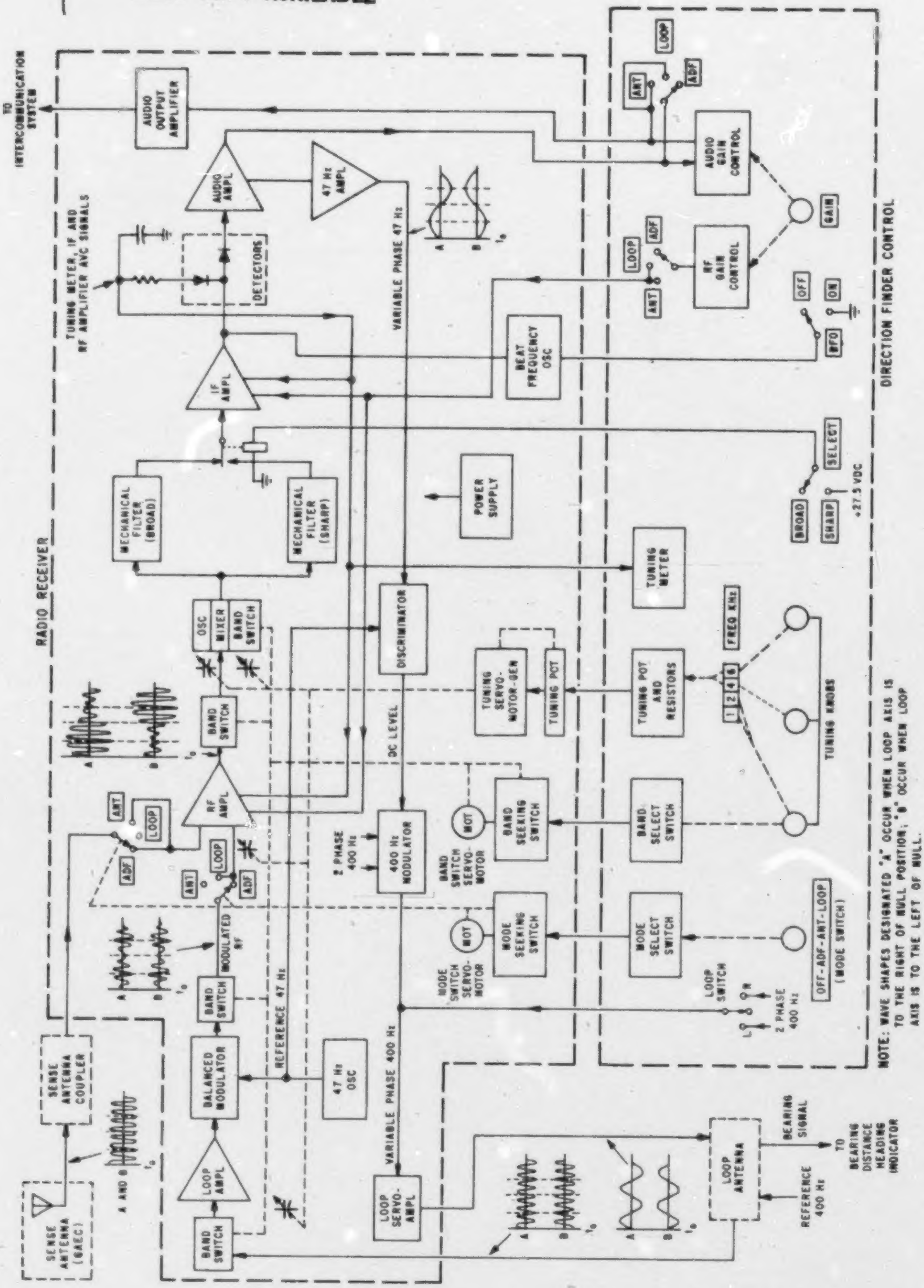
RADIO RECEIVER
DIRECTION FINDER CONTROL
TO INTERCOMMUNICATION SYSTEM
AUDIO OUTPUT AMPLIFIER
AUDIO AMPL
47 Hz AMPL
TUNING METER, IF AND RF AMPLIFIER AVC SIGNALS
DETECTORS
VARIABLE PHASE 47 Hz
IF AMPL
BEAT FREQUENCY OSC
MECHANICAL FILTER (BROAD)
MECHANICAL FILTER (SHARP)
POWER SUPPLY
TUNING METER
OSC
MIXER
BAND SWITCH
DISCRIMINATOR
DC LEVEL
TUNING SERVO-MOTOR-GEN
TUNING POT
TUNING POT AND RESISTORS
FREQ KHz
1 2 4 6
TUNING KNOBS
RF AMPL
ANT
LOOP
ADF
2 PHASE 400 Hz
400 Hz MODULATOR
MOT
BAND SEEKING SWITCH
BAND SWITCH SERVO-MOTOR
BAND SELECT SWITCH
MODE SEEKING SWITCH
MODE SWITCH SERVO-MOTOR
MODE SELECT SWITCH
OFF-ADF-ANT-LOOP (MODE SWITCH)
MODULATED RF
REFERENCE 47 Hz
LOOP SWITCH
2 PHASE 400 Hz
BALANCED MODULATOR
47 Hz OSC
SENSE ANTENNA COUPLER
SENSE ANTENNA (GAEC)
A AND B
LOOP AMPL
VARIABLE PHASE 400 Hz
LOOP SERVO-AMPL
LOOP ANTENNA
BEARING SIGNAL
REFERENCE 400 Hz
TO BEARING DISTANCE HEADING INDICATOR
AUDIO GAIN CONTROL
RF GAIN CONTROL
GAIN
OFF
ON
BFO
SELECT
BROAD
SHARP
+27.5 VDC
A
B
I_0
NOTE: WAVE SHAPES DESIGNATED "A" OCCUR WHEN LOOP AXIS IS TO THE RIGHT OF NULL POSITION; "B" OCCUR WHEN LOOP AXIS IS TO THE LEFT OF NULL.

AT. 330

Figure 10-26.—AN/ARD-13, simplified block diagram.

antenna has no output when in the null position. Either output phase of the loop antenna is modulated by a 47 Hz signal in the balanced modulator stage. The results of modulation for either phase input are shown.

The output of the balanced modulator is added to signals from the sense antenna by the RF amplifier. Note that there is a 180° difference in phase between the envelope of A, present when the loop antenna is to the right of the null, and envelope B, present when the loop antenna is to the left of the null. The output of the IF amplifier is amplified and detected, and is applied to the audio amplifier. The output of the audio amplifier is processed and applied to the 47-Hz amplifier.

The amplified 47-Hz component of the output of the audio amplifier is applied to the discriminator. The discriminator compares the phase of the 47-Hz signal from the 47-Hz amplifier with the reference phase from the 47-Hz oscillator. If the two are in phase, the discriminator applies a positive d-c level to the 400-Hz modulator. If the two are out of phase, the discriminator applies a negative d-c level to the 400-Hz modulator.

The 400-Hz modulator applies either phase A or phase B 400-Hz signal to the loop servo amplifier, which is connected to one winding of the loop antenna drive motor; phase A if the d-c level from the discriminator is positive, and phase B if the input from the discriminator is negative. Phase A causes the loop antenna to rotate to the left, phase B to the right. Thus, the signal that drives the loop antenna motor will always cause the loop antenna to rotate toward the null position.

The bearing indicator, electromechanically coupled to the loop antenna by synchros, reads the position of the loop and thus the direction to the signal source.

In the ADF mode, the RF gain control is inoperative. The audio gain control is used to vary the audio output level of the receiver.

Equipment Capabilities

As with any type of electronics equipment, the actual effectiveness of the AN/ARD-13 depends on the design characteristics, the installation details, the qualifications of the operator, and the quality of the maintenance performed. Design features may eliminate many problems; but within the design limits of the equipment, maintenance and calibration determine its actual effectiveness. The maintenance practices and procedures, as prescribed in the appropriate technical manuals for the equipment and for the aircraft in which it is installed, must be adhered to.

Calibration

The radiofrequency field pattern in the vicinity of the aircraft is distorted by the configuration of the aircraft itself. This distortion varies with respect to the earth's magnetic field, with the heading of the aircraft, and with the electromagnetic fields resulting from the operation of various equipment.

Although it is possible to compensate for many factors while on the ground, the final calibrations should be done in the air. It must be repeated when the operating area of the aircraft is changed. The procedure is elaborate and time consuming, but it is essential if the full value of the equipment is to be realized. For details concerning the calibration procedure, consult the appropriate volume of the Maintenance Instructions Manual for the specific model aircraft.

OTHER ADF EQUIPMENTS

AN/ARN-41A Direction Finder

Radio Receiving Set AN/ARN-41A is a combination automatic direction finder and radio receiver designed for use in aircraft. When signals from the sense antenna alone are selected, the equipment functions as a conventional radio receiver for continuous-wave and amplitude-modulated signals. When signals are selected from both the loop and sense antennas, the equipment functions as an automatic direction finder (ADF), providing automatic visual and aural indications of the relative direction from which radio signals are being received. The equipment frequency range is from 190 kHz through 430 kHz and from 480 kHz through 1725 kHz. This is covered in three bands. The equipment may be used as an ADF or radio receiver on all its bands.

The AN/ARN-41A can be used for homing on a single station, or for triangulation position fixing using two or more stations, or for position fixing on a single station using any of the double bearing methods presently in use. Only ground waves of the transmitting station are used in ADF operation.

AN/ARA-25 UHF Direction Finder

The AN/ARA-25 is an ultrahigh frequency ADF that is used on most naval aircraft having UHF transceivers.

Desirable performance of the AN/ARA-25 and its relative freedom from serious maintenance problems have proven it to be a reliable homing equipment. Accurate bearings on received signals at relative bearings of 000° and 180° are rapidly obtained; and while this is being accomplished, communication with the UHF station is interrupted for only short periods of time. Bearings at other than 000° or 180° relative are not as accurate due to deviation.

The heart of the AN/ARA-25 ADF is the directional antenna. Because of the design of the antenna, no sense antenna is necessary. The AN/ARA-25 antenna is a flat, diamond-shaped (rhombic) plate placed over a tapered cavity. (See fig. 10-27.) The cavity is designed to maintain a 50-ohm characteristic impedance at frequencies in the range of 225 MHz to 400 MHz.

INTEGRATED ELECTRONIC CENTRAL SYSTEMS

Although many aircraft retain the communication, navigation, and identification equipments as separate components, there is a trend to equip military aircraft with integrated communications-navigation-identification (CNI) subsystems. These integrated electronic packages are commonly referred to as CNI systems although some publications refer to them as IEC (integrated electronic central) systems.

A typical CNI subsystem will contain a UHF communications and ADF section, an IFF/SIF identification section, a TACAN section, a central control section, and a common power supply. An exception to the use of a common self-contained power supply is the TACAN subsystem which usually has its own integral power supply.

The UHF communications and ADF section will use one or more UHF transceiver units,

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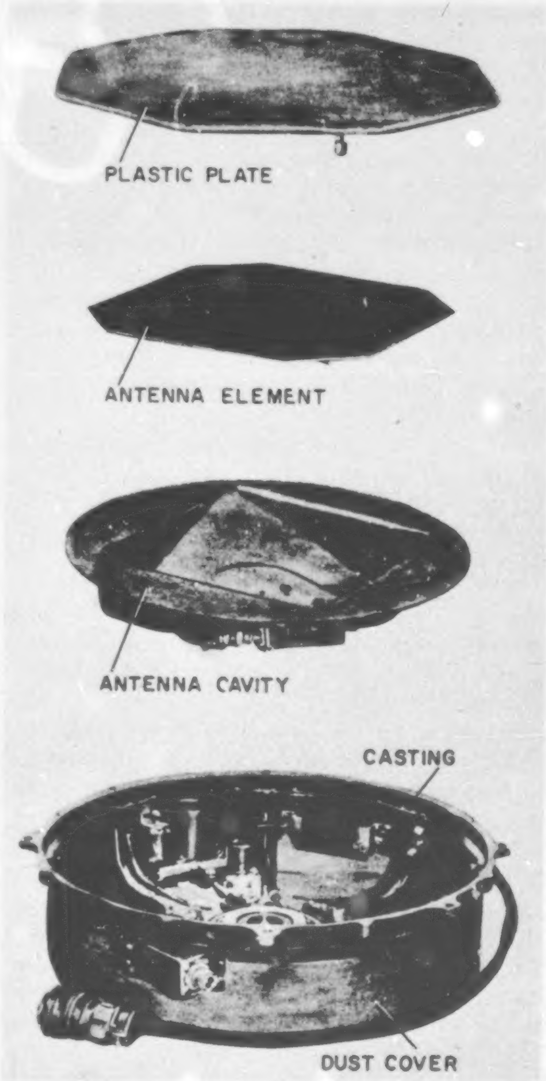


AT. 331

Figure 10-27.—AN/ARA-25 antenna, disassembled.

permitting voice communications on any of the 1,750 channels in the frequency band between 225.0 and 399.9 MHz. One or more of these transceivers will contain a guard channel receiver subsystem section. An auxiliary UHF receiver may be installed to allow separation of the ADF from the normal communication channel. One of the transceivers may be used as part of a digital data link system. The IFF/SIF (identification, friend or foe and selective identification feature) and TACAN sections operate in a manner similar to those covered in this manual.

The integration of these subsystems reduces weight and space requirements and allows for a more centralized control. In general, at least four separate antennas are needed for a CNI system: a TACAN antenna, an IFF antenna, a communications antenna, and an ADF antenna.

In addition to its control of the sections named, the central control section will normally control the ICS (intercommunication system) also.

For more information concerning IEC or CNI systems, refer to the appropriate maintenance instruction manual for a particular aircraft or piece of equipment.

CHAPTER 11

AIRBORNE RADAR

The objective of this chapter is to provide a general coverage of the various uses of radar and the hazards that the AT may encounter in the operation and maintenance of radar equipment.

REVIEW OF RADAR PRINCIPLES

The term radar is used to describe electronic systems which are used to locate airborne or surface targets. A review of the introduction to radar in Basic Electronics, Vol. 2, NavPers 10087-C, reveals that the word RADAR is an acronym formed from the words RAdio Detection and Ranging. In addition to indicating the presence of targets, radar may also be used to determine bearing, distance, elevation, speed, relative size, and identification. The accuracy of each use of radar is determined by several characteristics.

BASIC CHARACTERISTICS

Range

Radar measurement of range or distance is possible because of the fact that radiated RF energy travels through space in a straight line at a constant velocity. The straight path and constant speed are changed slightly when the RF waves enter the atmosphere and will vary with atmospheric and weather conditions. (This is discussed later in this chapter.)

VELOCITY.–RF energy travels at the speed of light, about 186,000 statute miles (162,000 nautical miles) per second. This is 300,000,000 meters per second in the metric system. Radar timing is usually expressed in microseconds, and the velocity of radar waves is often given as 328 yards or 984 feet per microsecond.

One nautical mile is equal to approximately 6,080 feet. This means that it takes RF energy approximately 6.18 microseconds to travel 1 mile.

RANGE MEASUREMENT.–The pulse type radar set determines range by measuring the elapsed time during which the emitted pulse travels to the target and returns. Since two-way travel is involved, a total time of 12.36 microseconds per nautical mile will elapse between the start of the pulse from the antenna and its return from a target. The range in nautical miles of any object can be found by measuring the elapsed time for a round trip of the radar pulse (in microseconds) and dividing this quantity by 12.36. In equation form, this is:

$$\text{Range} = \frac{\text{elapsed time}}{12.36}$$

Minimum Range.–The minimum range capability of a radar is determined by the time of the transmitter pulse, or pulse width (PW), plus the recovery time of the duplexer and the receiver. (For purposes of this explanation, recovery time may be considered as the time required for the receiver to become operative after the transmitter has fired.)

The minimum range in yards, at which a target can be detected, is equal to the PW plus the recovery time, divided by 2 and multiplied by 328 yards (328 yd/μsec). Stated in a formula:

$$\text{Minimum range} = \frac{\text{PW} + \text{recovery time}}{2} \times 328 \text{ yd}$$

$$= (\text{PW} + \text{recovery time}) \times 164 \text{ yd}$$

where PW and recovery time are in microseconds. Targets closer than this range are not seen because the receiver is inoperative for the period of time necessary for a signal to travel this distance.

An increase in recovery time (bad TR tube in the duplexer) not only increases the minimum range, but also decreases the receiver sensitivity.

Maximum Range.–The higher the frequency of a radar wave, the greater the attenuation (decrease in signal strength) due to weather effect. Gases and water vapor that make up the atmosphere absorb energy from the radiated pulse. Frequencies below 3000 MHz are not appreciably attenuated under normal conditions, while frequencies above 10,000 MHz are highly attenuated. Attenuation of the transmitted pulse results in a decrease in the ability of the radar to produce usable echoes at long ranges. A usable echo may be defined roughly as the smallest signal which a receiver-indicator system is able to detect, amplify, and present so that the observer can visually distinguish it from the noise signals on the CRT (cathode-ray tube).

At lower frequencies, higher transmitter power can be developed more easily. Also, there is greater refraction and diffraction (bending of the waves). Lower radar frequencies are therefore superior for extremely long-range search radar. The effect of atmospheric conditions on radar signals is discussed in more detail later in this chapter.

The maximum range of any radar depends upon transmitted power, pulse repetition frequency, and receiver sensitivity. The peak power of the transmitted pulse determines the maximum range that the pulse can travel to a target and return in usable echo strength. Sufficient time must be allowed between transmitted pulses for an echo to return from a target located at the maximum range (established by design) of the system.

The maximum range is sometimes extended and vertical coverage reduced by the trapping of the radar beam in a DUCT. A duct is created by abnormal weather conditions; further coverage on ducts is given later in this chapter.

Azimuth

The azimuth (bearing) of a target is its clockwise angular displacement in the horizontal plane with respect to true north as distinguished from magnetic north. This angle may be measured with respect to the heading of an aircraft containing the radar set; in this case, it is called relative bearing. The angle may be measured from true north, giving true bearing, if the installation contains azimuth stabilization equipment. The angle is measured by utilizing the directional characteristics of an unidirectional antenna, and determining the position of the antenna when the strongest echo is received from the target.

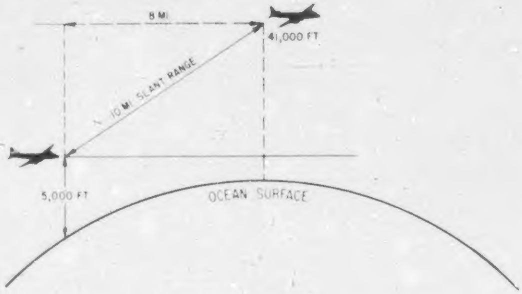
Radar antennas are constructed of radiating elements and reflectors, and some types use a director element to produce a narrow beam of energy in one direction. The pattern produced in this manner permits the beaming of maximum energy in a desired direction. The transmitting pattern of an antenna system is also its receiving pattern. An antenna can therefore be used to transmit energy, to receive echoes (reflected energy), or both.

Resolution

The range resolution of a radar is the minimum resolvable separation in range of two targets on the same bearing. Range resolution is a function of the width of the transmitted pulse, the type and size of the targets, and the characteristics of the receiver and indicator. With a well-designed radar, sharply defined targets on the same bearing should be resolved if their ranges differ by the distance the pulse travels in one-half of the time of the pulse width (164 yards per microsecond of PW). If a radar set has a pulse width of 5 microseconds, the targets would have to be separated by more than 820 yards before they would appear as two pips on the scope.

The azimuth resolution is the ability to separate targets at the same range but on different bearings, and is a function of the antenna beam width and the range of the targets. Antenna beam width may be defined as the angular distance between the half-power points of an antenna's radiation pattern. (Half-power points are those points at which the transmitted power is one-half the maximum value of energy that is radiated along the lobe center.) Two targets at the same range, in order to be resolved as being two targets instead of one, must be separated by at least one beam width.

Strong multiple targets appearing as one target can often be resolved in azimuth and bearing by reducing the gain of the receiver until only the strongest portions of the echoes appear on the CRT.



AT. 338

Figure 11-1.—Slant range versus horizontal range.

Accuracy

The accuracy of a radar is a measure of its ability to determine the correct range and bearing of a target. The degree of accuracy in azimuth is determined by the effective beam width and is improved as the beam width is narrowed. On a PPI (plan position indicator) scope the echo begins to appear when energy in the edge of the beam first strikes the target. The echo is strongest as the axis of the beam crosses the target, but the echo continues to appear on the scope as long as any part of the beam strikes the target. The target appears wider on the PPI display than it actually is, and the relative accuracy of the presentation depends in a large measure on the width of the radar beam and range to the target.

The true range of a target is the actual distance between the target and the radar set (fig. 11-1). In airborne radar, the true range is often called SLANT RANGE. The term slant range is used to indicate that the range measurement includes the effect of difference in altitude.

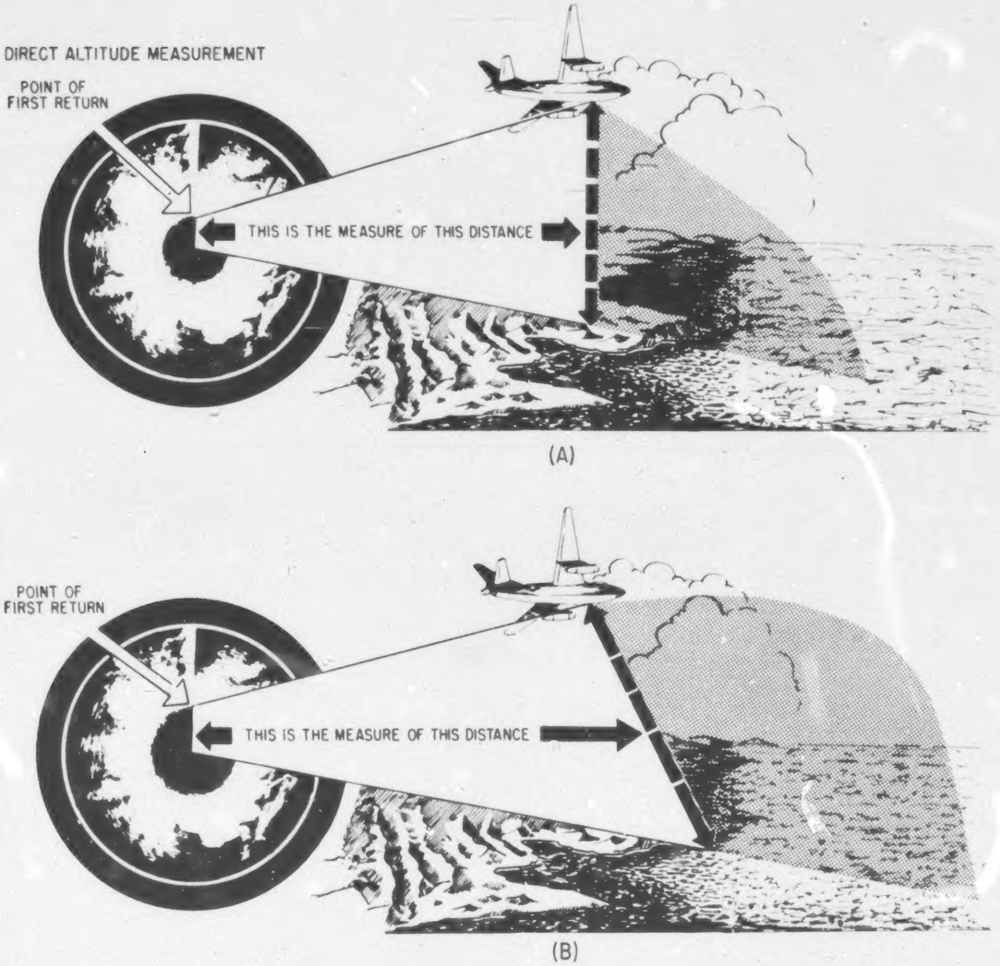
The horizontal range of a target is a straight line distance (fig. 11-1) along an imaginary arc parallel to the earth's surface. This concept is important to the radar observer because an airborne target, or the observer's aircraft, need only to travel the distance represented by its horizontal range to reach a position directly over its target. For example, an aircraft at a slant or true range of 10 miles, and at an altitude of 36,000 feet above the radar observer's aircraft, possesses a horizontal range of only 8 miles.

The timing sequence of a radar range indicating device starts at the same instant that the transmitter starts operation. Therefore, with airborne surface-search radar, the first targets seen are those directly beneath the aircraft. However, on the PPI scope, there is a hole (altitude ring) in the middle of the picture (fig. 11-2), with a minimum radius corresponding to the altitude of the aircraft. In some systems the radius of the altitude ring will vary as the lower limit of the vertical radiation pattern is increased by raising the tilt of the radar antenna. Objects which are actually directly beneath the aircraft appear on the scope at a distance equal to the distance between the aircraft and ground. For greater accuracy of surface ranges, the relationship between the range of the target and the range of the altitude ring must be considered.

FACTORS AFFECTING RADAR

There are many factors, or elements (including atmospheric conditions), that affect radar performance. One of the principal factors is maintenance. The ability to keep the equipment operating at peak efficiency will influence the overall capabilities and limitations of the radar.

Another important factor is the radar opera-


DIRECT ALTITUDE MEASUREMENT
POINT OF FIRST RETURN
THIS IS THE MEASURE OF THIS DISTANCE
(A)
POINT OF FIRST RETURN
THIS IS THE MEASURE OF THIS DISTANCE
(B)

AT. 339

Figure 11-2.–Effect of altitude on radar. (A) Radar tilted down; (B) radar with zero tilt.

tor's knowledge of the equipment. He must know the maximum and minimum ranges at which he can expect to pick up various targets, range and bearing accuracy of the gear, and range and bearing resolution. If the radar is a height finder, the operator must know the altitude determination accuracy and the altitude resolution. Information on these factors is contained in the Maintenance Instructions Manual for each radar.

Peak Power

The peak power of a radar is its useful power. Range capabilities of the radar will increase with an increase in peak power. Doubling the peak power (a 3-db gain) will increase the range capabilities by about 25 percent.

Pulse Width

The longer the pulse width, the greater the range capabilities of the radar. This is due to the greater amount of RF energy sent out in each pulse. In addition, consider the fact that narrow bandpass receivers may be used, thus reducing noise level. An increase in pulse width, however, reduces the range resolution capabilities of the system.

Beam Width

The beam width is specified in degrees between the half-power points in the radiation pattern.

The effective beam width of a radar is not a constant quantity because it is affected by the receiver gain (sensitivity) and the size and range of the target.

The narrower the beam width, the greater the concentration of energy. The more concentrated the beam, the greater the range capabilities for a given amount of transmitted power.

Receiver Sensitivity

The sensitivity of a receiver is a measure of the ability of the receiver to amplify and make usable a very weak signal. The more sensitive the receiver, the greater the detection range of the radar. Sensitive receivers are easier to jam, however, and interference will show on the scope more easily.

Indicators

The choice of the type of scope used to display weak pips will add to the capabilities of the radar. The deflection-modulated A-scope is more sensitive to weak echoes than the intensity-modulated PPI. In some airborne installations that carry an oscilloscope for maintenance purposes, a weak target can be seen on the A-scope before it can be detected on the PPI.

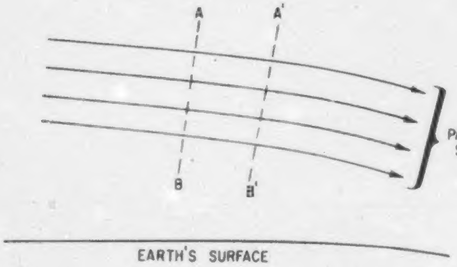
Antenna Rotation

The more slowly the antenna rotates, the greater the detection range of the radar. Thus, an antenna which is not rotating would afford the greatest range in the direction it is pointing, within the limits of the radar. For tactical reasons, it is best not to stop the antenna from rotating and point the antenna beam at the target, except momentarily, and then only to gain information on composition of a target.

Atmospheric Conditions

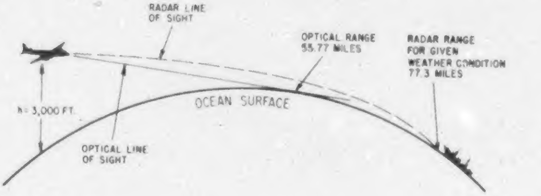
The paths followed by microwave and VHF signals, whether direct or reflected, usually are slightly curved. The signals travel through the atmosphere at speeds that depend on temperature, atmospheric pressure, and the amount of water vapor present in the atmosphere. Generally, the higher the temperature the faster the signal; the lower the atmospheric pressure, the faster the signal; and the less the amount of water vapor present, the faster the signal. The net result of these influences is that the signal speed changes with altitude and, under normal atmospheric conditions, the variation is a small and uniform increase in the speed of the signal with increasing altitude. This causes all paths to curve slightly downward, as shown in figure 11-3, extending the radar horizon beyond a tangent to the earth. (See fig. 11-4.) The amount of the extension of the radar horizon varies with weather conditions. Under normal conditions, the radar horizon is extended 1.25 times the optical line of sight.

To understand the reason for this curving downward, imagine a surface called a wave front such as the one represented by line AB (fig. 11-3), where A is higher in altitude than B. A wave front is a surface, not necessarily flat, chosen in such a way that the phase of the signal is the same at all points on the surface. The signal always travels in a direction perpendicular to the wave front. Now, as wave front AB moves with the signal, it reaches position A'B' after a short time interval. The speed at A and A' is faster than the speed at B and B', since A and A' are at a greater altitude. Therefore, in a given time, the upper part of the wave front moves



AT. 340

Figure 11-3.—Microwave path.


RADAR LINE OF SIGHT
OPTICAL RANGE 55.77 MILES
RADAR RANGE FOR GIVEN WEATHER CONDITION 77.3 MILES
h = 3,000 FT.
OCEAN SURFACE
OPTICAL LINE OF SIGHT

AT. 341

Figure 11-4.—Extension of radar horizon.

farther than the lower part, and the wave front tips slightly forward as it moves along. Since the path followed by the signal is always perpendicular to the wave front, it curves slightly downward as the wave front tips.

The bending of radio or radar waves due to a change in the density of the medium through which they are passing is termed refraction. The measure of the bending that occurs is indicated by the difference in index of refraction from one substance to another. The density of the atmosphere changes at a gradual and continuous rate; therefore, the index of refraction changes gradually with increased height.

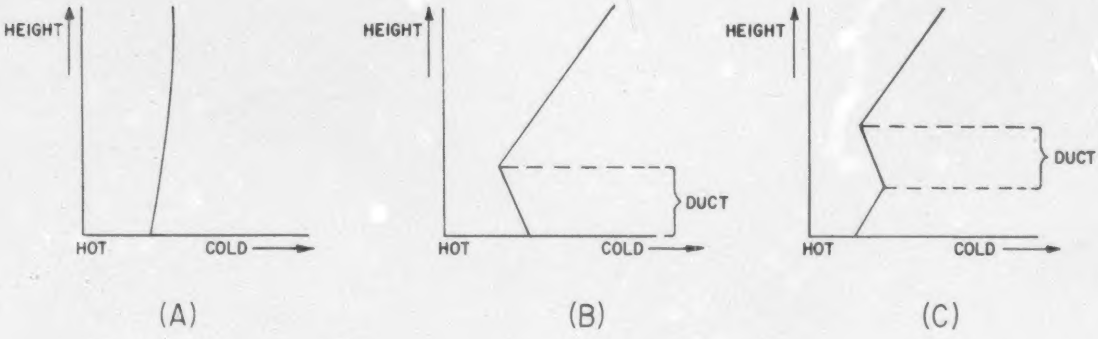
The temperature and the moisture content of the atmosphere normally decrease with height above the surface of the earth. Under certain conditions, the temperature may first increase with height and then begin to decrease. Such a situation is called temperature inversion. More important, the moisture content may decrease more rapidly with height just above the sea. This effect is called moisture lapse.

Temperature inversion or moisture lapse, alone or in combination, may produce a great change in the index of refraction of the lowest few hundred feet of the atmosphere, resulting in greater bending of the radar waves. This may greatly extend or reduce the radar horizon, depending on the direction in which the radar waves are bent. The height of the radar antenna with respect to the DUCT formed by this strange occurrence is of much importance.

Although duct conditions can happen any place in the world, the climate and weather in some areas make their occurrence more likely. In some parts of the world, particularly those having a monsoonal climate, variation in the degree of duct formation is mainly seasonal, and great changes from day to day may not take place. In other parts of the world, especially those in which low barometric pressure areas recur often, the extent of nonstandard propagation conditions varies considerably from day to day, even during the season when they are most common.

Sometimes, for various reasons in different areas, some upper level air becomes heated and often partially dried out. This effect is associated with clear weather rather than with storms. The temperature inversion and a layer of very dry air, which spreads out horizontally, create conditions favorable to the formation of a sky duct. The top of a duct can often be recognized by a thin layer of haze. The haze is a result of the moisture in the warm air condensing as the air starts to get colder.

The height and width of ducts can be predicted by the meteorological office. This is done by plotting temperature variations versus height. Figure 11-5 shows a standard variation chart compared with charts of nonstandard conditions.



AT. 342

Figure 11-5.—Height versus temperature. (A) Standard variation; (B) surface duct; (C) sky duct.

TYPES OF AIRBORNE RADAR

The fundamental principles of all radar are similar; however, there are two basic types of radar systems—pulse and CW (continuous wave). FM radar is a type of CW radar. The Doppler principle can be used in both CW and pulse radars. The distinction between CW and pulse radar becomes less clear in systems where a combination of pulse and CW techniques is used. In general, a radar system is considered a pulse system when the RF energy is emitted less than 10 percent of the time. Most pulse radars emit energy less than 0.1 percent of the time. When the radar emits energy more than 10 percent of the time, it is classified as a CW radar system.

Most of the emphasis in radar development has been on pulse radar systems, primarily because of the rate at which information is collected, as compared to CW radar. However, there are specific applications in which CW radar performs more efficiently than pulse radar; for example, working to zero range and reduction of ground clutter.

Radar is a powerful aid to the aircraft, and the aircraft is an aid to the radar. The aircraft supplies an elevated platform to the radar, thereby extending the effective range at which objects can be detected. The application of radar to airborne operations has been most successful and airborne radar is an indispensable part of the Navy's fighting team. In naval aircraft, radar has many different uses, each requiring a different application of the fundamental principles.

SEARCH

Search radar, the basic type used in many radar-equipped aircraft, shows the range and azimuth of targets such as ships, islands, coastlines, and other aircraft within the reach of its beam. Search radar is an effective aid to air navigation since it exhibits land masses and storm clouds on the radar screen. In larger aircraft the IFF (identification friend or foe) interrogation antenna is mounted on the search radar antenna in order to obtain IFF target bearing and range, which identifies ships and aircraft as friendly or hostile by means of coded replies.

Airborne search radar is generally classified as medium range. Figure 11-6 indicates the relative positions of the search radar operating frequencies. The pulse width utilized by the radar is variable, depending on the range selected—on shorter ranges a narrow pulse width (0.5μsec) is used; longer ranges may use a pulse width up to 5μsec. The narrow pulse width permits a short minimum range, a high degree of range resolution, and greater range accuracy. The wide pulse

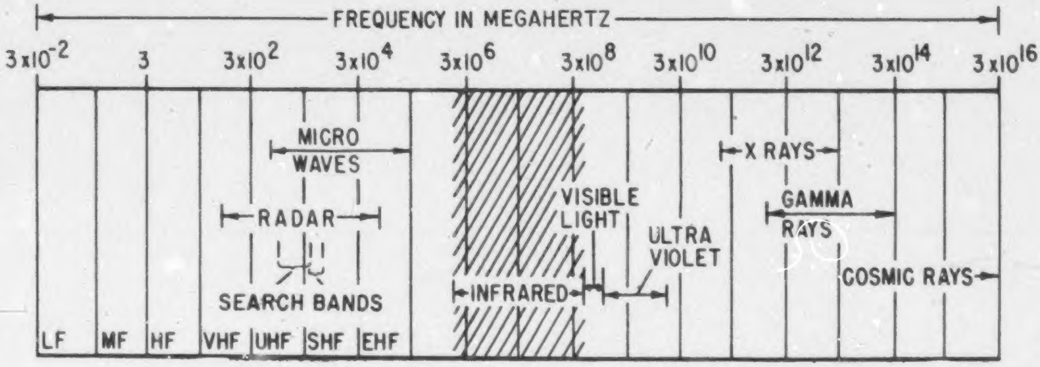


Figure 11-6.—Electromagnetic energy spectrum.

width is used to aid in detecting small targets at greater distances.

In some radar equipments the pulse repetition frequency (PRF) of the radar may also vary with the ranges used—high PRF is used on the shorter ranges for better target illumination, and a low PRF is used for obtaining greater maximum ranges.

HEIGHT FINDING

Height-finding radar is used to determine the altitude of a target by placing a narrow vertical beam on the target and measuring the position angle. The position angle is combined with the slant range to compute the altitude of the target above the horizontal. In airborne use the computed altitude of the target may be either the height above your aircraft or the height above ground. For computation of the target's altitude above ground, the altitude of your aircraft must be set in.

Another type of height-finding radar is the absolute altimeter. The absolute altimeter (radar altimeter) measures the distance from the aircraft to the ground or objects below. This is done by transmitting RF energy down, and receiving the reflected energy at the aircraft. In FM equipment the altitude is determined by the frequency difference between the reflected signal and the transmitter signal. In pulse equipment the altitude is determined by measuring the time required for the transmitted pulse to hit the ground and return. The indicating instrument will indicate the true altitude of the aircraft, which is its height above water, mountains, buildings, or other objects on the surface of the earth.

SIDE-LOOKING RADAR

The surveillance and mapping of large areas and the capability of providing data which permits rapid and accurate identification, location, and interpretation of all important features within the areas surveyed are of vital importance today. Since airborne radar can operate during night or day, under adverse weather conditions, and with the mobility and range of an airborne platform, radar ground mapping systems are ideal. Side-looking radar (SLR) systems have proved to offer many advantages over other radar ground mapping systems.

Purpose

The side-looking radar system provides photographic data which is displayed by reflected microwave energy rather than by reflected light. Although the film resolution of SLR photographs does not compare with that of standard aerial photographs, the SLR photography is capable of displaying data which would not appear on a standard photograph; for example, the detection of a hard target (gun emplacement) under camouflage material where the reflection of microwaves would show up clearly on the recording. The system also provides a map of the terrain which can aid in filling questionable gaps on photographic information. Because SLR is side-looking, it has an inherent security-against-detection advantage when compared with forward looking radar since the radiation from the parent aircraft will not be detected until the aircraft is passing the target.

NAVIGATION

Doppler navigational radar automatically and continuously computes and displays groundspeed and drift angle of an aircraft in flight without the aid of ground stations, wind estimates, or true airspeed data. This is done by utilizing auxiliary inputs from an altitude rate sensor and from the aircraft's vertical reference system. The radar section does not sense range and bearing (direction) as ordinary search radar does. Instead, it is speed-conscious and drift-conscious. It employs continuous carrier wave transmission energy and determines the forward and lateral velocity components of the aircraft by utilizing the principle known as Doppler effect.

The Doppler effect, or frequency change of a signal, is discussed in chapter 3 of this manual.

Doppler radar employs the frequency change phenomenon, except that it operates in the radio frequency range. The radar emits CW energy at one frequency, and these waves of energy strike the target and are reflected. Energy waves returning from the target are spaced differently than the transmitted waves if there is relative motion between the radar and the target. A closing target moves a little closer to the radar between successive waves and reflects the waves sooner than if the target were stationary. The closer-spaced waves mean that the frequency has increased slightly.

If the target moves toward the radar or if the radar moves toward the target at a faster rate, the waves of energy will be even closer together when appearing at the receiver, causing a greater frequency change. The greater the closing speed, the higher will be the frequency of the returning waves.

The receiver of the Doppler radar system has two signal inputs—one from the transmitter, and one from the receiver antenna. The input signal from the transmitter is at all times the same frequency as the signal being radiated; the receiver antenna signal frequency will vary with the relative speed of the target and the radar. The two frequencies are compared in the receiver, and the difference frequency is a direct indication of the closing or opening speed of the target.

The Doppler effect is present any time there is relative motion (opening or closing distance) between the radar and the target. Therefore, the radar could be moving toward a stationary target and the effect would be the same as if the target were moving toward a stationary radar.

One type of airborne Doppler navigation equipment is an all-weather, self-contained system. It radiates two narrow, fixed beams of CW energy downward, outward, and rearward (thus the ground becomes an opening target) from the aircraft's longitudinal axis. The ground-returned energy is intercepted by the receiver and compared with the outgoing transmitter energy. The difference (due to the Doppler effect) is used to develop velocity component information for use in the computing section. The velocity component, with the aid of roll-angle, pitch-angle, altitude, and altitude-rate data furnished from auxiliary equipment, derives the groundspeed and drift angle in the computing section.

The groundspeed and drift angle information is continuously displayed on an indicating dial. It is also made available as a continuous synchro output signal for tie-in with other navigational equipment—position computers, bomb directors, and integrated flight director systems.

RF RADIATION HAZARDS

Electromagnetic radiation is not visible; its presence must be detected and measured by instruments or approximated by theoretical calculations. Radiated beams of high power RF energy present a health and safety hazard. In general, health and safety factors fall into the ordnance, personnel, fuel, and miscellaneous aspects. The establishment of health and safety precautions regarding electromagnetic radiation is a joint responsibility of the Bureau of Medicine and Surgery, the Naval Air Systems Command, and the Naval Ship Systems Command. Publications which may prove valuable for further reference include Radio-Frequency Hazards Manual, NavOrd OP3565 (a Confidential manual), and Electronics Installation and Maintenance Book–General, NavShips 0967-000-0100.

The energy striking an object in an electromagnetic field may be reflected, transmitted, or absorbed; only the absorbed energy constitutes a hazard. The hazard resulting from focused concentration of such energy, like any hazard, can be rendered relatively harmless by understanding and precaution.

To locate specific safety instructions for a particular aircraft, the AT must consult the appropriate maintenance instruction manual. A typical hazardous area is shown in figure 11-7. Notice that the tabular information is applicable to fixed antenna positions. If the antenna is in motion the "a" sector must move accordingly.

ORDNANCE HAZARDS

The HERO (hazards of electromagnetic radiation to ordnance) problem has become acute. The number and variety of electrically initiated explosive devices are increasing rapidly. For example, some currently operational weapons contain more than 75 electroexplosive devices. Continuing development efforts are directed toward reducing weight and space requirements, lowering power requirements, assuring positive response, and increasing safety and reliability. However, these goals are not always complementary.

At the same time, the power of communications and radar transmitting equipment is constantly being increased and the frequency spectrum broadened. The radiofrequency spectrum now used by the airborne Navy extends from 10 kHz to about 20,000 MHz. Transmitter power outputs extend to 10 kw at communications frequencies, and peak power outputs extend to approximately 5 megawatts at radar frequencies.

These trends produce situations which are in direct conflict with each other. Transmitters and their antennas have only one purpose–to radiate electromagnetic energy. The initiating elements of ordnance devices need only to be supplied with the proper amount of electrical energy for an explosion to take place. Therefore, with many explosive ordnance items, certain precautions are required for safety and to insure reliable performance.

To meet the growing need for new procedures to reduce the hazard to ordnance equipment from RF radiation, the Naval Air Systems Command has sponsored tests which, coordinated with studies made by other agencies, have provided new guidelines and restrictions for handling electrically initiated ordnance equipment.

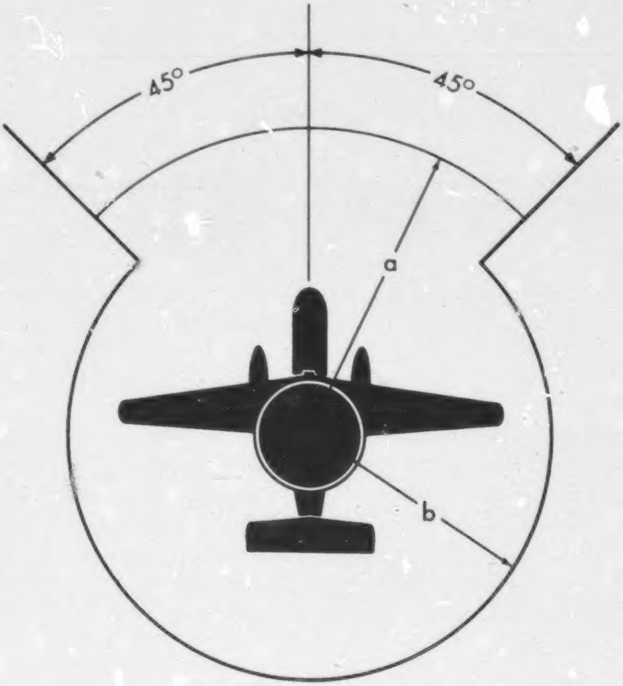
The basic problem in determining an ordnance system's susceptibility to RF radiation lies in the evaluation of the antennalike couplings that exist between illuminating fields and the electroexplosive devices in the system. RF energy may enter a weapon as a wave radiated through a hole or crack in the weapon skin, or it may be conducted into the weapon by the firing leads or other wires leading into the weapon.

The exact chances of an electroexplosive device firing are quite unpredictable, being dependent upon such variables as frequency, field strength, positional and directional orientation, environment, and metallic or personnel contacts with the ordnance or aircraft.

The most susceptible period is during assembly, disassembly, loading, unloading, or testing in electromagnetic fields. The most likely effects of premature actuation are dudding, reduction of the reliability of the device, or propellant ignition. In extreme cases, there is a definite possibility of warhead detonation.

Some specific safety precautions which the technician must observe with respect to these weapons and ordnance devices include the following:

1. Turn off all RF transmitters during weapon handling operations in the area.
2. Observe all local and general safety and HERO restrictions.
3. Maintain radio and radar silence for assembly, disassembly, loading, unloading, or testing operations.
4. Avoid illumination of ordnance devices by high power RF transmitters (fig. 11-7).



MAIN BEAM AXIS
(ANTENNA IN FIXED POSITION)

MINIMUM DISTANCE (FEET) TO BE MAINTAINED FROM OPERATING RADARS

PERSONNEL		UNARMED AIRCRAFT VEHICLES BUILDINGS		FUELING AND DEFUELING OPERATIONS		ARMED AIRCRAFT EXPLOSIVE DEVICES ARMAMENTS	
a	b	a	b	a	b	a	b
170	20	250	30	1000	150	1500	300

TRANSMISSION ABOARD CARRIER

TRANSMITTING ABOARD CARRIER IS NOT RECOMMENDED. IF TRANSMISSION IS NECESSARY A DUMMY LOAD MUST BE USED. DISTANCES LISTED IN THE ABOVE TABLE MUST BE STRICTLY ADHERED TO IF DUMMY LOAD IS NOT USED.

AT. 13

Figure 11-7.—Radar transmission danger areas.

The HERO problem is a complex one. The hazard, and therefore the solution, is a function not only of frequency and field strength, but also of geometrical configuration, orientation, and the antenna characteristics of the weapon or weapon-aircraft and weapon-launcher combinations. In general, the path by which energy is introduced to the electroexplosive devices is not readily definable.

Development projects are underway in several areas to provide special devices and material which will have general application as HERO remedies. It is expected that some of these devices, and some developed by other agencies, will be valuable in the design of new weapons as well as modifications for existing weapons. Many possibilities have been and are being explored. These include shielding, filters, RF dissipating attenuators, less sensitive electroexplosive devices, exploding wires, conductive film igniters, spark gap primers, inductive firing devices, and modifications to aircraft armament circuits.

PERSONNEL HAZARDS

Development of RF systems with high power transmitting tubes and high gain antennas has increased the hazard to personnel in the vicinity of these elements. Harmful effects of overexposure to RF radiation are associated with the average power of the absorbed radiation. They are thermal in nature and are observed as an increase in overall body temperature or as a temperature rise in certain sensitive organs of the body. The only known nonthermal effects on personnel are due to power density values considerably greater than the power densities normally associated with present RF transmitting systems.

The Bureau of Medicine and Surgery has established safe limits based on the power density of the radiation beam and the exposure time of the human body in the radiation field. All areas in which the RF levels exceed the safe limits are considered hazardous. The Naval Ship Systems Command is responsible for determining hazardous shipboard areas and for decreasing the hazard to personnel from RF radiation. Theoretical calculations and power density measurements are used to establish the distances from radar antennas within which it is not biologically safe for personnel to enter. This information is then used to determine if and where hazardous areas exist. All hazardous areas subject to entry by personnel are posted with warning signs, and the ship's intercommunication system is used to warn personnel when the radars are operating.

Personnel Safety Precautions

While every effort must be made to protect personnel from harmful exposure to RF radiation, it is not considered necessary or desirable, in general, that blanket restrictions on antenna radiation be imposed to achieve this end. The existence of such a policy would tend to restrict maintenance and checkout procedures which could otherwise be carried out in safety, provided proper precautions are taken to keep personnel clear of hazardous intensity levels. These precautions include the following:

1. Visual inspection of feed horns, open ends of waveguides, and openings emitting RF electromagnetic energy must not be made unless the equipment is definitely secured for the purpose of such an inspection.
2. Aircraft employing high power radar should be parked, or their antennas should be oriented, so that the beam is directed away from personnel working areas.
3. All personnel must observe RF hazard warning signs which point out the existence of RF radiation hazards in a specific location or area.
4. Those radar antennas which normally rotate are to be rotated continuously while radiating, or trained to a known safe bearing.
5. Nonrotating antennas must be trained and elevated away from inhabited areas, hangars, shop spaces, ships, piers, etc., while radiating.
6. Where a possibility of accidental overexposure might still exist, have a man stationed within view of the antenna (but well out of the beam and in communication with the operator while the antenna is radiating) to warn personnel of the hazard.
7. Radiation hazard warning signs should be available and must be used, not only where they

are required to be permanently posted, but also where they may temporarily restrict access to hazardous areas.

FUEL HAZARDS

The increase in radiated RF energy from higher powered communications and radar equipments in recent years has increased the potential hazard of RF-induced ignition of volatile fuel-air mixtures. This flammable condition is normally present only close to aircraft fuel vents, open fuel inlets, or spilled fuel, or during over-the-wing fueling operations. Ignition of fuel vapors in air has actually occurred; however, the probability of ignition with normal refueling conditions is remote.

Ignition of gasoline vapors caused by RF-induced arcs is rare because ALL the following conditions must exist:

1. A flammable fuel-air mixture must be present within the range of the induced arcing.
2. The arc must contain a sufficient amount of energy to cause ignition.
3. The gap across which the arc occurs must be a certain minimum distance, and must contain a sufficient amount of the flammable mixture to ignite.

The possibility of these conditions occurring simultaneously is probably statistically remote; but since the possibility does exist, care must be exercised. See figure 11-7 for minimum distances to be maintained during fueling and defueling operations.

MISCELLANEOUS ASPECTS

The firing of photoflash bulbs, fluorescent lamps, and neon glowlamps by electromagnetic energy from radar sets is a fairly well known phenomenon. Although this type occurrence is normally of little consequence, burns can result. Photographic personnel should be warned of the presence of any high power radar operating in the area and of the hazards involved.

In a similar manner, steel wool may be set afire, or metallic chips may produce sparks when exposed to radiation. With some high power radar sets, steel wool is ignited with a violent explosion. The presence of oil and spilled fuels in the vicinity of aircraft constitutes a serious hazard. This makes good housekeeping procedures essential.

PRINCIPLES OF IFF

The age-old problem of distinguishing friend from enemy in warfare increased greatly when aircraft came into use. As faster ships and aircraft developed, the identification problem increased. Although a radar can detect targets (both sea and air) at long ranges, it displays both friend and enemy as similar spots of light on the CRT. With the destructive power of modern weapons and the speed of modern weapon delivery systems, it is not practical to wait until the target has been identified by visual means to begin preparing for battle. Therefore, some method other than visual recognition must be used to identify the target as early as possible.

The problem of identification led to the development of an electronic system that permits a friendly craft to identify itself automatically when interrogated, before approaching near enough to threaten the security of other naval units. This electronic system is called IFF (identification, friend or foe). Additionally, in the present state of high density air traffic, even though operations involve only friendly aircraft, it is essential to know not only their location but also the identity of each aircraft and their approximate altitude.

IFF systems are designated by MARK numbers. The IFF mark number is a Roman numeral such as the Mark X or Mark XII system.

IFF SYSTEM

The basic theory of operation is similar to that of the TACAN system discussed in chapter 10. In the TACAN system, the aircraft initiates proceedings by interrogating a ground station which in turn replies to that interrogation. In other words, TACAN works "aircraft-to-station-to-aircraft." IFF is just the reverse; that is, it goes "station-to-aircraft-to-station."

The IFF system consists basically of a pair of special transmitter-receivers, working in conjunction with a radar set. Figure 11-8 shows the units required for the basic operation of an IFF

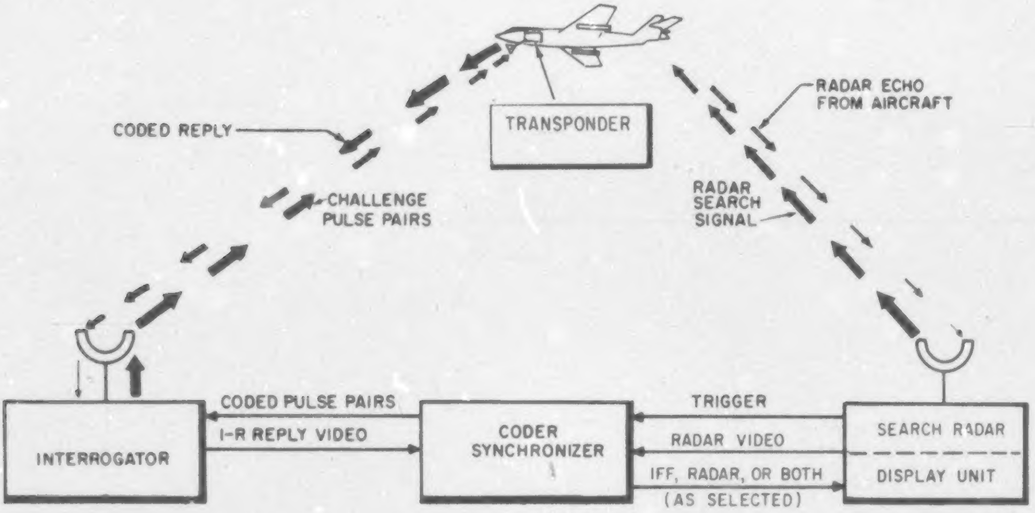

TRANSPONDER
CODED REPLY
CHALLENGE PULSE PAIRS
RADAR ECHO FROM AIRCRAFT
RADAR SEARCH SIGNAL
CODED PULSE PAIRS
I-R REPLY VIDEO
INTERROGATOR
CODER SYNCHRONIZER
TRIGGER
RADAR VIDEO
IFF, RADAR, OR BOTH (AS SELECTED)
SEARCH RADAR
DISPLAY UNIT
AT. 302

Figure 11-8.–IFF system block diagram.

system. Reference to this figure should be made at frequent intervals throughout the remainder of this discussion.

The challenging control center consists of an interrogator, a coder-synchronizer, a search radar unit and a display unit. The aircraft, in order to satisfy the interrogator and thereby complete the "loop", is equipped with a radar transmitter-receiver (transponder) and associated auxiliary equipment which is determined by specific aircraft configuration. It should be noted at this time that all aircraft IFF systems are not configured in the same manner, and reference to any specific IFF transponder and its associated auxiliary equipment will not be made in this chapter. For additional information the technician should refer to the appropriate maintenance instruction manual for a specific aircraft.

Interrogation

The interrogator is a pulse type transmitter, triggered by the coder-synchronizer, which acts as the challenger. When a radar operator observes an unidentified target on the radar, he sets the interrogator in operation and it emits coded challenging (interrogation) pulses.

The challenge is a pair of UHF pulses emitted a few microseconds after the radar pulse. The challenge signals are synchronized with the pulse of the associated radar, but with a delay of 0 to 40 microseconds introduced.

The challenge is received by the transponder, which is a pulse type transmitter-receiver unit. Upon receiving the proper challenge, the transponder automatically transmits an identifying reply. These multiple-pulse replies from the interrogated aircraft are routed to the coder-synchronizer where they are analyzed to determine their validity. If interpreted to be proper, they are processed into a form acceptable to the display unit and a visual presentation is then generated for operator interpretation.

When displayed on the radar CRT, the video pulses may be displayed separately, or they may be mixed with the radar presentation if desired.

The composite airborne replies are displayed on a PPI scope as dashed lines beyond the target echo. (See figure 11-9.) The dashed effect is due to the mode interlacing action of the coder. Blank spaces on the scope represent the time during which interrogations on the other modes are sent out. The IFF presentation can be distinguished from the radar presentation by these dashes. The length of the dashed line varies with the range and the radiation pattern of the antenna used with the challenging control center. In some installations the Mode-2 reply will be a double-dashed line beyond the target echo.

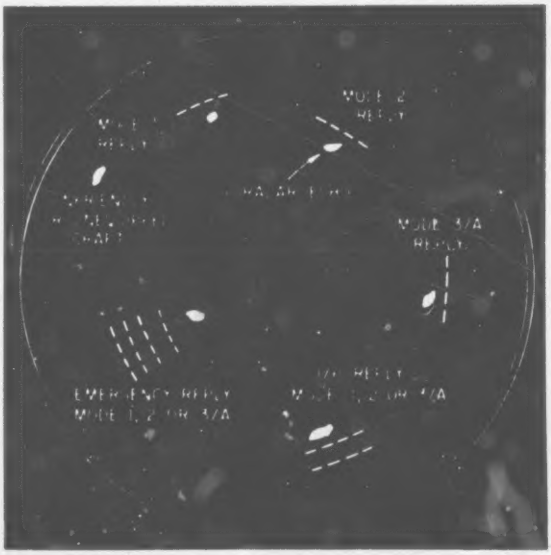
Modes of Operation

In systems employed by the United States, there are presently six types (or modes) of challenging signals mode-1, mode-2, mode-3/A, mode-4, mode-C, and mode-D (fig. 11-10). Also illustrated is a seventh mode (mode-B) which is used only in Great Britain at this time.

The civilian aircraft system corresponding to IFF is called Air Traffic Control Radar Beacon System (ATCRBS), often referred to as simply BEACON. The civil system for identifying modes uses letters rather than the numerical system adopted by the military. Since civil mode "A" is the same as our mode-3, this mode (commonly used by both for Air Traffic Control) has been designated "3/A". Mode-4 has no counterpart in the civilian ATCRBS system. It is a cryptographically secure mode with entirely different signal characteristics.

Modes 1 and 2 are also for exclusive use by the military as tactical modes, but use similar signal characteristics as shown in figure 11-10. Following mode-4, the military dropped its numerical sequencing and adopted the civil designations as demonstrated by mode-C and mode-D. Mode-C is used for automatic altitude reporting and mode-D has been established but not yet given a definite designation.

As an example of mode operation, assume that both the interrogator (ground) and the interrogated aircraft are in mode 3/A. In this event the two units will be operating on compatible time frames of 8 microseconds between mode pulses (fig. 11-10), and they will correspond with each other. Keep in mind that these pulse-pairs from the interrogator occur only once after each time the search radar transmits, and comprise but a small portion of the normal time period between search radar pulses.



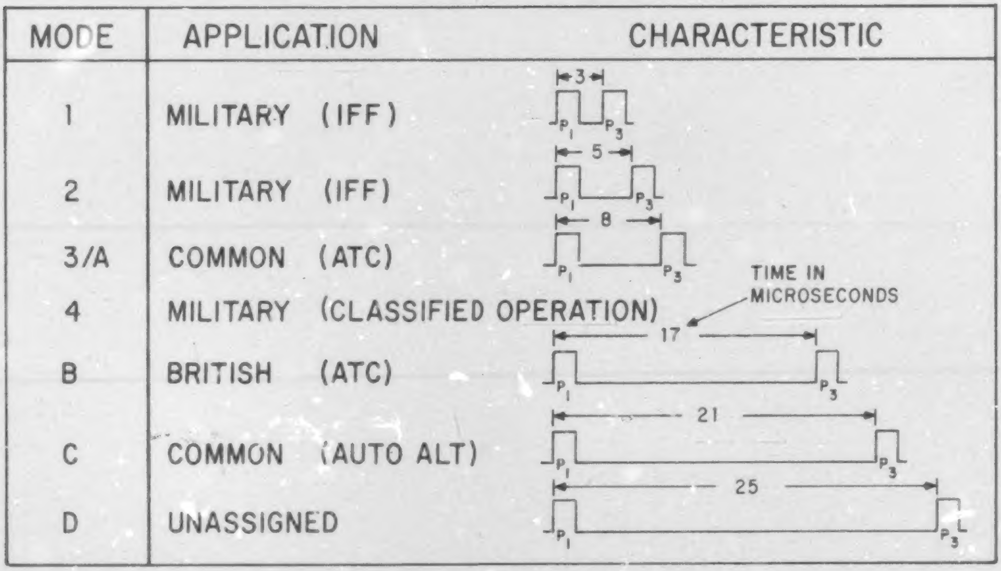
AT. 14

Figure 11-9.—Typical surface radar PPI composite display showing several IFF responses.

To this point the means of locating the aircraft (the search radar shown in figure 11-8) and of establishing a communicating link between the two units (pulse-pairs of compatible time frames) has been discussed. Positive identification of the interrogated target is accomplished through a feature of the aircraft's transponder (or auxiliary unit) referred to as selective identification feature (SIF) and the interrogators recognition of the SIF outputs. This feature has led to the common usage of the designation IFF/SIF.

Selective Identification Feature

When the interrogator and interrogated systems are operating on the same mode, an additional portion of the time between search radar pulses is used to develop an identification procedure. This time is filled by predetermined groups of pulses as shown in figure 11-11.



AT. 15

Figure 11-10.—Interrogation modes.

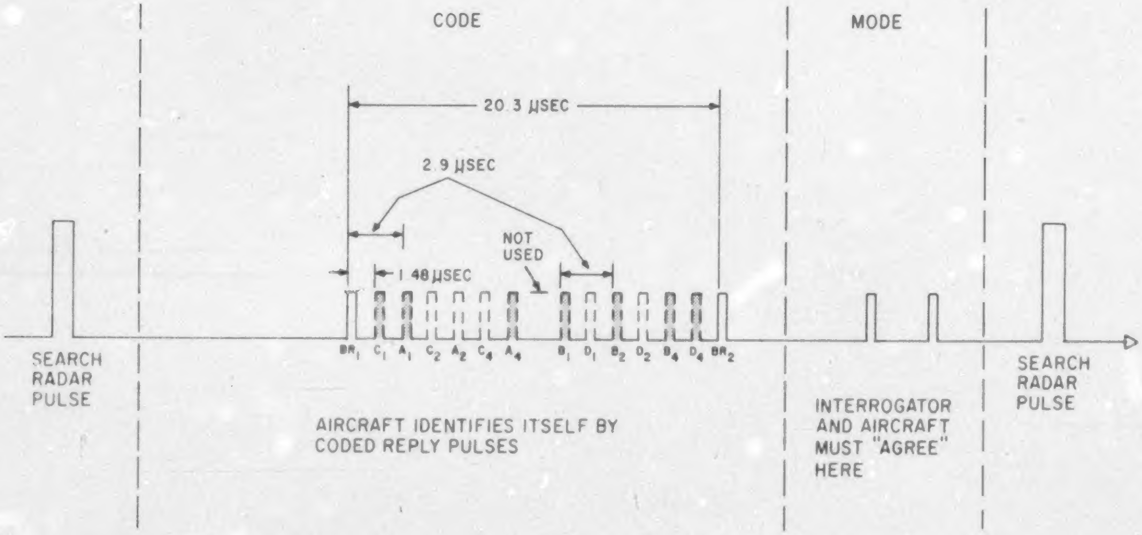
There are 32 separate codes which can be transmitted on mode 1. Mode 2, 3/A, and C each have 4,096 codes assigned. The minimum code which can be transmitted on mode 1, 2, 3/A, or C consists of two pulses spaced 20.3 microseconds apart. These two pulses, called framing or bracket pulses, are designated BR1 and BR2 in figure 11-11 and are always transmitted on any of the four modes, thereby bracketing the information pulses. Mode 1 uses five information pulses, A_1, A_2, A_4, B_1, and B_2 with an interpulse spacing of 2.9 μ sec. For modes 2, 3/A and C there are 12 information pulses which can be used. These include all of the A, B, C, and D pulses shown with an interpulse spacing of 1.45 microseconds. Note that a pulse is missing between A_4 and B_1. This void is termed the X-pulse position. An X pulse is used only for special applications and normally is not included in IFF/coder equipment.

Since there are many different code arrangements possible, a method of specifying a particular code has been established. Each information-pulse position has been assigned a letter and a number subscript. The code designation of a specific code is determined by adding the numbers corresponding to each letter. Since there are four letters involved—i.e., A, B, C, and D, there are four numbers in the code. The first digit of the code is determined by the A pulses, the second digit by the B pulses, etc. For example, if the code consists of A_1, A_4, B_1, B_2, B_4, C_1, and D_4, pulses (fig. 11-11), the code would be specified as 5 7 1 4. Keep in mind that these numbers are constructed in binary form, that is:

$A_1 \quad A_4 \qquad B_1 \quad B_2 \quad B_4 \qquad C_1 \qquad D_4$

$5 \qquad\quad 7 \qquad\quad 1 \qquad 4$

and must be read out in that form. If the code consisted of the A_1, A_2, and B_1 pulses, the code would be specified as 3100. The codes for mode


CODE
MODE
20.3 µSEC
2.9 µSEC
NOT USED
1.48 µSEC
BR1 C1 A1 C2 A2 C4 A4 B1 D1 B2 D2 B4 D4 BR2
SEARCH RADAR PULSE
AIRCRAFT IDENTIFIES ITSELF BY CODED REPLY PULSES
INTERROGATOR AND AIRCRAFT MUST "AGREE" HERE
SEARCH RADAR PULSE

AT. 32

Figure 11-11.—SIF code configurations.

1 range from 0000 to 7300 and from 0000 to 7777 for modes 2, 3/A and C. Some of the more common SIF codes with which you should be familiar are listed below:

1100 2000	climbing
1500 2200	descents
3100	hijacked
4000	any aircraft
4100 4200	most military aircraft
7600	lost communication
7700	emergency
1000	changing altitudes

This does not mean that in every case these codes are assigned as shown. Some are always used as shown; others are normally used as shown. As mentioned, there are 4,096 separate codes possible in modes 2, 3/A, and C. This makes available many different codes for arbitrary selection or temporary assignments.

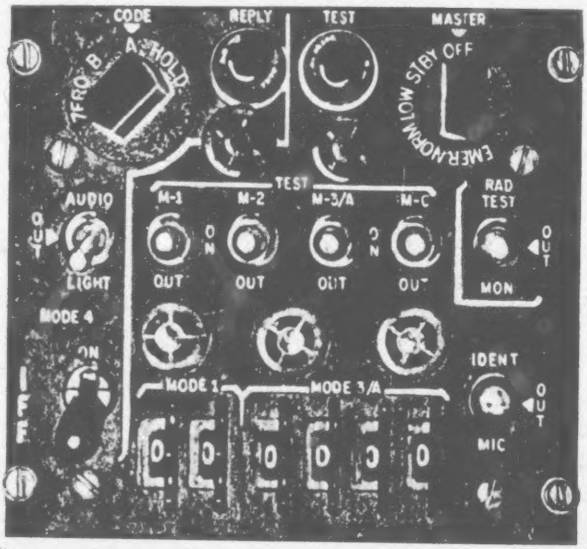
Mode 4 consists of a continuous chain of encrypted pulses and does not use the bracketing system of pulse pairs. It should be remembered that U. S. systems have no provisions for modes B and D. They have been included in this chapter only in the interest of continuity.

Often, FAA assigns "blocks" of codes to various agencies for special use, such as a naval facility from which student pilots are learning to fly. These codes are then instrumental in bringing to the controller's attention the special nature of such flights. A typical IFF/SIF control panel is shown in figure 11-12.

Notice the rotary switches and their associated number-windows in the center-bottom of the panel. These switches are used to set in the desired codes.

When the IDENT/OUT/MIC switch is in the IDENT position, the transponder transmits an additional pulse train. This double pulse train transmission permits even further identity, such as picking one particular aircraft out of a formation flight. The MIC position also causes the transponder to reply with a second pulse

BEST COPY AVAILABLE


CODE
ZERO
B
A
HOLD
REPLY
TEST
MASTER
OFF
STBY
LOW
NORM
EMER
AUDIO
LIGHT
OUT
TEST
M-1
M-2
M-3/A
M-C
ON
RAD TEST
MON
MODE 4
ON
IFF
MODE 1
MODE 3/A
IDENT
MIC

AT. 36

Figure 11-12.—IFF/SIF control panel.

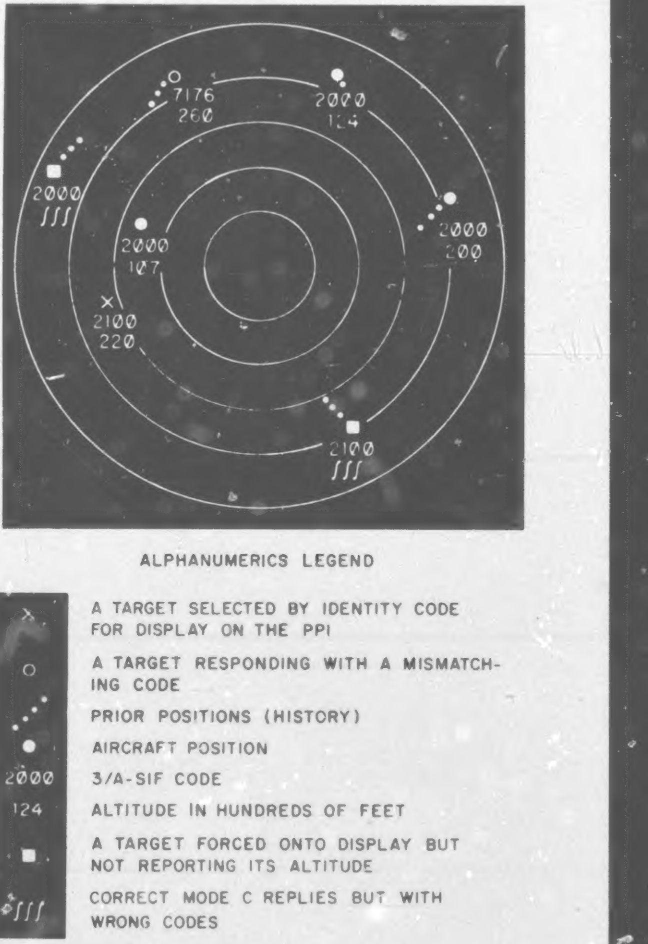
train when the microphone switch is depressed. The double pulse trains generated by the responding aircraft appear on the controller's screen as symbols that are even more definitive than those provided by the single pulse train replies.

AIMS

The AIMS program which began several years ago, had a twofold purpose: to satisfy FAA air traffic control requirements and to improve military IFF systems. AIMS is an acronym made up of other acronyms.

A . . . . ATCRBS
I . . . . IFF
M . . . . Mark XII identification system
S . . . . System

When all military aircraft are eventually outfitted with a 4,096 code capability, thus facilitating the use of mode-C, the air traffic controller will be able to exercise improved control and provide more expeditious services.


7176
260
2000
124
2000
∫∫∫
2000
107
2000
200
2100
220
2100
∫∫∫

ALPHANUMERICS LEGEND

×	A TARGET SELECTED BY IDENTITY CODE FOR DISPLAY ON THE PPI
○	A TARGET RESPONDING WITH A MISMATCHING CODE
• • •	PRIOR POSITIONS (HISTORY)
●	AIRCRAFT POSITION
2000	3/A-SIF CODE
124	ALTITUDE IN HUNDREDS OF FEET
■	A TARGET FORCED ONTO DISPLAY BUT NOT REPORTING ITS ALTITUDE
∫∫∫	CORRECT MODE C REPLIES BUT WITH WRONG CODES

AT. 38

Figure 11-13.—DAIR display.

DAIR

A further step in the direction of traffic control improvements is the Direct Altitude and Identity Readout (DAIR) system. With the implementation of the AIMS program, aircraft equipped with at least a Mark X IFF/SIF system, and operating in modes 3/A and C can cooperate with a DAIR system. Mode 3/A (via SIF) identifies the aircraft and mode-C automatically transmits the altitude. Figure 11-13 shows a hypothetical DAIR display as might be used by the controller.

It must be recognized at this point that (1) the aircraft, when equipped, can operate in more than one mode at a time and, (2) that to provide all the DAIR information the aircraft equipment MUST be operating in both mode-3/A and mode-C.

This system provides the controller with instantaneous identities and altitudes of all targets on his scope, thereby reducing his workload and allowing him to concentrate more on controlling traffic than on gathering information. It also brings to his immediate attention emergency/unusual conditions, insuring prompt assistance, in addition to greatly reducing the verbal communications. With such positive control available it is normal for the controller to permit discontinuation of position reports.

By 1975, all FAA enroute traffic control centers and several terminal areas in the U.S. will be automated. Also projected for this time frame is the installation of TPX-42 (DAIR) equipment at all Navy and Air Force control facilities not served by the FAA.

Future improvements of DAIR include terminal and enroute facilities which will be notified automatically of applicable IFR flights via data-link. All IFR traffic will thus be coordinated throughout the continental U. S. Eventually this plan is envisioned to be so inclusive as to cover all aspects of IFR flights from takeoff to landing.

CHAPTER 12

ELECTRONIC COUNTERMEASURES

It is the purpose of this chapter to introduce the general principles involved in the operation of electronic countermeasures devices. In the discussion which follows, examples of countermeasures equipments are described to illustrate these principles. The descriptions of the units included here are not intended to provide detailed information concerning maintenance and operation, but are given solely to present the broad basic facts which are common to many examples of countermeasures equipments, both old and new.

It is a basic rule of warfare that for each weapon used by the enemy a counterweapon must be developed. This rule is clearly expressed in modern war by the development and use of electronic countermeasures. The counterweapon in this case is used against enemy electronic equipment, radar, communication transmitters and receivers, navigation aids, and electronically controlled weapons (such as guided missiles and proximity fuses). The objective of ECM is to make the enemy's use of these electronic devices ineffective.

The Navy is presently engaged in a major electronic countermeasure (ECM) modernization program. It is extending the coverage of its deception ECM (DECM) into higher frequencies, extending coverage of tactical jammers, installing DECM equipment on its ASW aircraft and starting development on a new internally-housed avionics track-breaking minijammer. To keep abreast of new developments it is necessary that the AT become familiar with the fundamental concepts of electronic countermeasures.

SIGNAL CHARACTERISTICS

To prepare effective countermeasures against communication systems, navigation aids and weapons systems, information is needed concerning the frequencies of the emissions, the types of modulation used, the polarization of the transmitted waves, and the exact locations of the stations. For countermeasures against enemy radar, much more information is required. The principal signal characteristics or fingerprints of importance are the carrier frequency, the pulse repetition frequency, the pulse width, the type of scan employed, the rate of scan, and the beam width and polarization of the antenna.

CARRIER-FREQUENCY

Determination of the carrier frequency is the first step in analyzing an enemy radar. The probable function and platform of the intercepted signal can be predicted based on this information. Higher frequencies experience more atmospheric attenuation of the signal; therefore long range early warning radars typically utilize lower frequency transmitters. In addition, wavelength and therefore frequency play an important role in antenna and waveguide design. The longer the wavelength the larger the antenna must be; consequently airborne and submarine radars, where antenna size and weight are important considerations, normally use higher frequency transmitters. Additionally, knowledge of the carrier frequency is necessary for preparing an effective jamming operation.

PULSE REPETITION FREQUENCY

Another distinguishing characteristic of the radar is its pulse repetition frequency (PRF), which is the number of pulses emitted per second. The PRF is a major factor in determining the maximum range of the unit since it governs the time interval between the pulses. Long range air search radars must necessarily use low PRF values, since the pulses need to be spaced at intervals sufficient to allow echo signals to return from the most distant object within the desired range. Higher values of PRF are used in surface-search radars designed for detecting objects at shorter ranges. Extremely high pulse rates are employed in such equipment as fire control radars, which have very short range but extreme accuracy.

You should be aware that the PRF of an intercepted radar can change. An airborne radar may suddenly change from low to high PRF as it changes from long range to short range search or changes modes of operation. Also the PRF might jitter or be staggered from one pulse to the next. Such techniques are often employed for electronic counter countermeasure (ECCM) purposes.

PULSE WIDTH

It is desirable to know the pulse width of radar signals since this value is the basis for estimating the minimum range of the unit. Pulse width is the interval of time during which the radar transmitter is energized; as a result, it determines the minimum range at which target echoes can be received.

Knowing the PW often indicates the probable function of an intercepted radar. Narrow pulses of 1 microsecond or less indicate precision radars with good target resolution such as navigation and fire control radars. Wide pulses indicate long range early warning radars. Many radars, especially airborne radars, can select two or more different pulse widths and PRF's, depending on their use. Such a radar will use a medium pulse width for searching and then shift to a narrow pulse width when switching to a shorter range or attack mode.

TYPE AND RATE OF SCAN

The type of scan, the method by which the radar beam searches the target area, is a good indication of the nature and action of the radar. Types of scan include 360°, sector, lobe-switching, conical, and spiral scans. The simplest way of distinguishing the scan type is by listening to the intercepted signals. Signals from search radars usually cause a whine in the headphones, the tone being produced by the constant pulse rate. In a 360° scan, the signal strength varies periodically as the beam sweeps over the search aircraft. As long as the signal variations continue, the radar is searching; but if the sound becomes loud and steady, the indication is that the set has probably detected the search aircraft and is concentrating its attention on it. Fire control radars often use lobe switching in which the beam locks first to one side of the target and then to the other side. The shifting of the beam takes place rapidly and brackets the target while the radar compares the echoes from each beam position. Lobe switching is easily detected by visual indications of the signals on panoramic adapters, pulse analyzers, and direction finders. It also causes a characteristic chatter in the headphones as the beam position varies.

The rate of scan, or number of scanning sweeps made per minute, is related to the probable maximum range of the radar. Slow scanning is characteristic of long-range search sets, while short-range radars and fire control systems employ much higher scan rates. The rate is usually measured in terms of the time required for one scan. The signals are observed on the screen of a panoramic adapter or the scope of a direction finder. The operator logs the time interval between successive indications of maximum signal strength.

BEAM WIDTH AND POLARIZATION

The measure of the beam width gives an indication of the azimuth accuracy of the enemy set. The width of the beam, which is expressed by the number of degrees between the half-power points, is generally computed from data provided by automatic recorders which give information concerning the amplitude of the signals.

Recall from chapter 11 of this manual that bearing resolution is a function of beam width. The narrower the beam, the better the resolution. Long range search radars usually use wide beams while shorter range threats such as weapons control radars use narrow beams.

The polarization of the radar antenna is considered in planning effective methods of jamming. This characteristic can be determined by use of direction finders of the type which makes a visual display of the reception. The direction finder is equipped with two antennas—one polarized horizontally and the other vertically. Either antenna can be used for reception, and the polarization of the incoming signals is learned by comparing the patterns resulting from each.

A rough determination of polarization can be made by alternate shifting from vertical to horizontal receiving antennas. The antenna which is of proper polarization for the signal being received will provide an audible response indicating greater signal strength. Circular polarization will give approximately a uniform response on either antenna.

PASSIVE ECM

Passive ECM (PECM) operations are those which cannot be directly detected by the enemy; examples include electronic reconnaissance (ER) and search operations, in which enemy transmitters are detected and located and as many as possible of the signal characteristics are determined. Passive countermeasures also include evasive tactics taken to avoid detection, and methods of controlling the radiations from friendly equipments to prevent the enemy from using our signals for homing, direction finding, or for any other purpose.

SEARCH RECEIVERS

The success or failure of an intercept mission depends largely on the proper functioning of the search receiver, the basic type of passive countermeasures equipment. By means of the receiver, the ECM operator detects the presence of radar and radio emissions, monitors enemy transmissions, learns the types of modulation used, and records indications of relative signal strength.

Search receivers are designed for intercepting signals occurring throughout wide ranges of frequency. Receivers are usually equipped with several tuning units, each of which can be either manually tuned or automatically swept over a selected frequency sector by motor-driven tuning circuits.

Tape and film recorders are used to make records of the signals received by the associated search receiver as it is tuned rapidly through the spectrum. The recording, which is analyzed after the flight, gives information concerning the frequencies of the signals, the amplitude, and the time of reception.

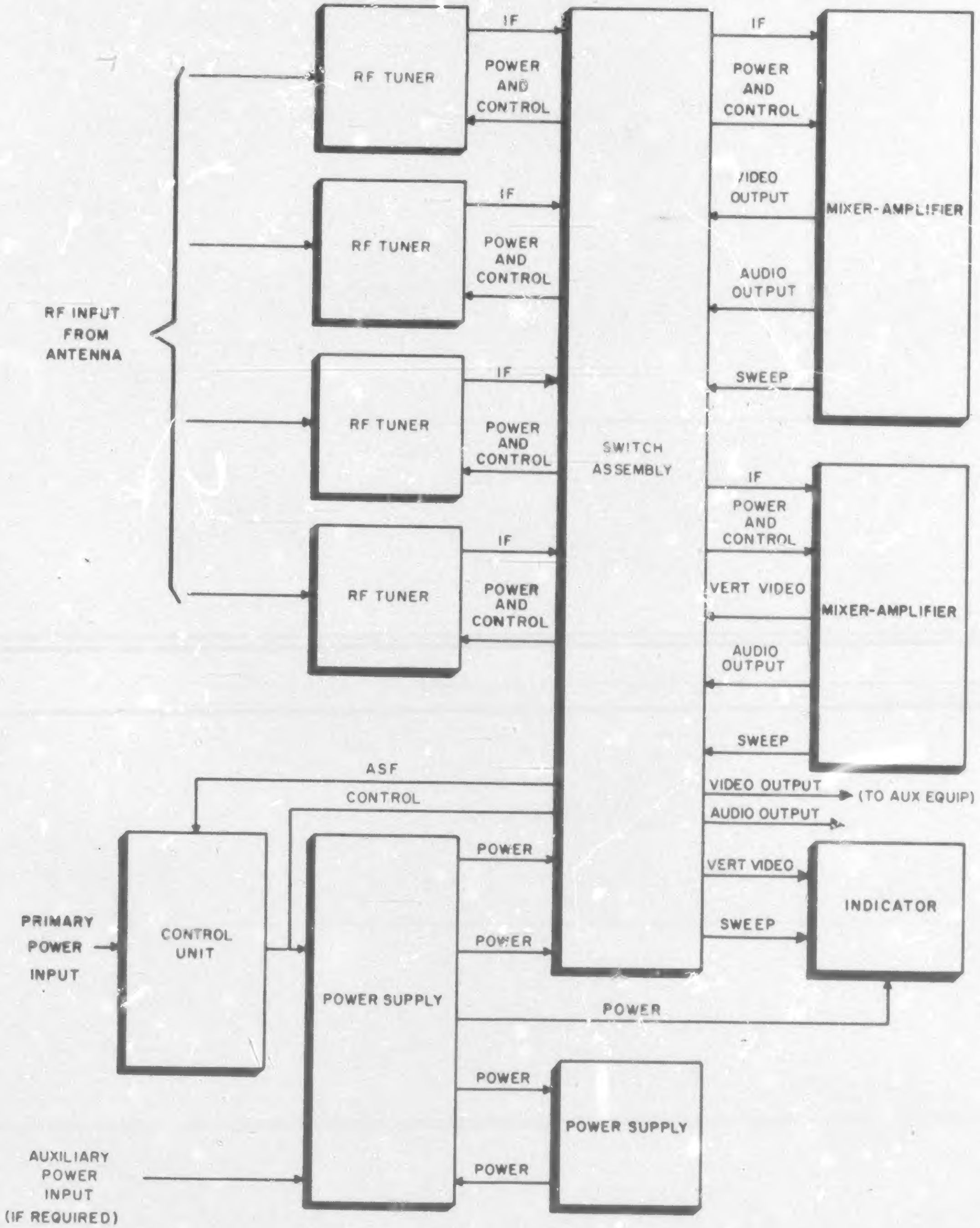
When searching for enemy radar locations, the ECM receiver operates at a fundamental advantage with respect to the radar. Radar detects objects by reflection, or two-way transmission, in which the reduction of signal strength is proportional to the fourth power of the distance covered by the waves. The receiver, on the other hand, detects the radar by a one-way transmission in which signal reduction is proportional only to the square of the distance. As a result, the presence of the radar can be detected at a distance greater than the maximum range at which the radar can detect the search aircraft.

Receiver Operation

Most search receivers employ superheterodyne circuits that can be tuned rapidly over various bands. The extremely wide frequency coverage required is provided by the use of several tuning units, each of which covers a part of the total tuning range of the receiver. Tuning units usually consist of a tuned antenna circuit, a local oscillator, and a mixer stage. The receiver produces three types of output-video signal voltages for use in a panoramic adapter, video signals which are applied to a pulse analyzer, and an audio output for the headphones. (A panoramic adapter is a cathode-ray indicator that enables the operator to sweep a broad spectrum of frequencies during a short period of time.) When a signal that the operator desires to inspect closely is displayed on the adapter, it is fed to the pulse analyzer for closer study.

In figure 12-1, a block diagram of a typical ECM superheterodyne receiver system is shown. The receiver covers a wide tuning range by employing several selectable RF tuners.

Signals intercepted by the antenna are fed to a connection on the receiver through a switching assembly. This assembly enables the operator to select the proper antenna for the frequency range to be covered. From the antenna connec-


RF INPUT FROM ANTENNA
RF TUNER
RF TUNER
RF TUNER
RF TUNER
IF
POWER AND CONTROL
SWITCH ASSEMBLY
MIXER-AMPLIFIER
MIXER-AMPLIFIER
VIDEO OUTPUT
AUDIO OUTPUT
SWEEP
VERT VIDEO
VIDEO OUTPUT
(TO AUX EQUIP)
AUDIO OUTPUT
INDICATOR
ASF
CONTROL
PRIMARY POWER INPUT
CONTROL UNIT
POWER SUPPLY
POWER
POWER SUPPLY
AUXILIARY POWER INPUT (IF REQUIRED)

AT. 38

Figure 12-1.—Typical multiple tuner block diagram.

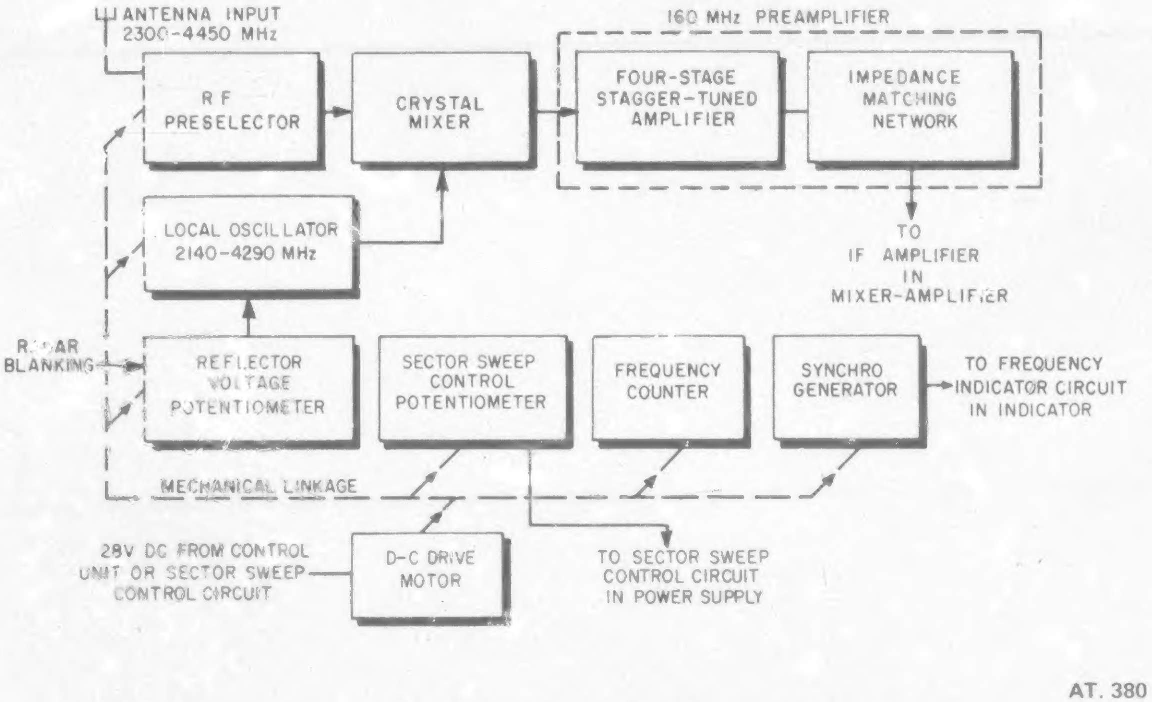
tion, the incoming signals are applied to one of the tuning units.

The tuning unit (fig. 12-2) contains an RF amplifier, a local oscillator, a crystal mixer, an IF preamplifier, and a d-c motor which is mechanically coupled to a synchro generator. The motor is also coupled to a counter which indicates the frequency to which the preselector is tuned. The synchro generator transfers frequency information to a cathode-ray indicator unit.

Since there are no manual controls in these tunings units, they are usually remotely mounted to provide better utilization of space in the aircraft. The d-c motor also automatically tunes the RF amplifier and the local oscillator through their frequency range. When the frequency is too high for use with conventional RF amplifier circuits, tunable cavities are incorporated instead. The popular name for these cavities is "RF preselector."

Mixing of the input signal with the signal from the local oscillator, in a crystal mixer, produces an IF frequency. This IF signal is amplified through several stages of preamplification. The preamplifiers are stagger tuned; that is, each stage of preamplification is tuned to a slightly different frequency. This staggered tuning gives a very broad bandpass which is desirable for video work. Impedance matching is used in the output to feed the signal into the next section, a mixer amplifier.

The mixer amplifier (fig. 12-3) contains a main IF amplifier strip, a second IF amplifier strip, and the video and audio circuits of the receiver. It also contains a sweep oscillator, a fixed oscillator, and beat frequency oscillator (BFO). The BFO is a heterodyning oscillator used for detecting CW or MCW transmissions. The sweep oscillator sweeps through a spread of frequencies equal to the receiver bandpass. The sweep oscillator output is mixed with the signal from the main IF amplifier in the mixer stage to produce a new and lower IF frequency. This system of going from one IF to a lower IF is called double conversion and is done to produce a still lower frequency which is easier to


ANTENNA INPUT
2300-4450 MHz
160 MHz PREAMPLIFIER
RF PRESELECTOR
CRYSTAL MIXER
FOUR-STAGE STAGGER-TUNED AMPLIFIER
IMPEDANCE MATCHING NETWORK
LOCAL OSCILLATOR 2140-4290 MHz
TO IF AMPLIFIER IN MIXER-AMPLIFIER
RADAR BLANKING
REFLECTOR VOLTAGE POTENTIOMETER
SECTOR SWEEP CONTROL POTENTIOMETER
FREQUENCY COUNTER
SYNCHRO GENERATOR
TO FREQUENCY INDICATOR CIRCUIT IN INDICATOR
MECHANICAL LINKAGE
28V DC FROM CONTROL UNIT OR SECTOR SWEEP CONTROL CIRCUIT
D-C DRIVE MOTOR
TO SECTOR SWEEP CONTROL CIRCUIT IN POWER SUPPLY

AT. 380

Figure 12-2.–RF tuner block diagram.

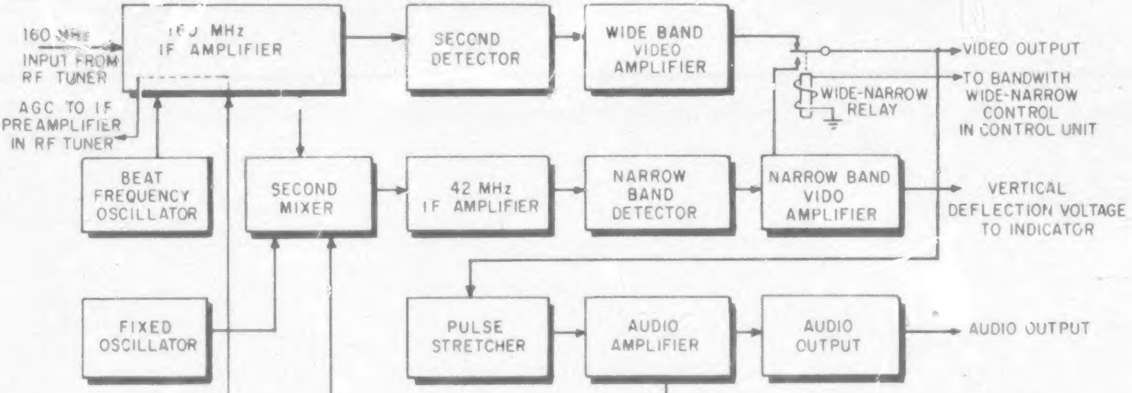
amplify. The lower frequency allows the use of simpler circuitry throughout the remainder of the receiver. This second IF signal is fed through several stages of amplification, then to a detector stage. The detector stage produces a video pulse which is available for presentation on the panoramic and pulse analyzer scopes.

During broadband operation the receiver may receive one or more signals simultaneously. In order to view one signal at a time, the receiver is switched to narrowband operation. Since it is mechanically difficult to stop the sweeping oscillator at the exact frequency needed for double IF conversion, a fixed oscillator is provided. The signal from the fixed oscillator is fed into the mixer during narrowband operation.

From the main IF amplifier strip a signal can be detected, amplified, and then made available as a video input for some auxiliary equipment such as a pulse analyzer, a direction finder, or a remote indicator. Provisions are also incorporated so that any signal present will be amplified through an audio circuit to give an audio tone. This tone may be used to aid the operator in detecting and evaluating signals. He can listen as well as look. This is desirable since eye fatigue is a problem when he must look at the scope continuously.

From the second IF of the mixer amplifier the video signal is fed to the CRT indicator for panoramic or pulse analyzer indication. The signal may also be fed to auxiliary equipment for further pulse analyzing or direction finding.

WAVE TRAPS.—Search receivers of the superheterodyne type often produce spurious responses caused by image reception in which a station is received at two different positions of


160 MHz
INPUT FROM
RF TUNER
AGC TO IF
PREAMPLIFIER
IN RF TUNER
160 MHz
IF AMPLIFIER
SECOND
DETECTOR
WIDE BAND
VIDEO
AMPLIFIER
VIDEO OUTPUT
TO BANDWITH
WIDE-NARROW
CONTROL
IN CONTROL UNIT
WIDE-NARROW
RELAY
BEAT
FREQUENCY
OSCILLATOR
SECOND
MIXER
42 MHz
IF AMPLIFIER
NARROW
BAND
DETECTOR
NARROW BAND
VIDO
AMPLIFIER
VERTICAL
DEFLECTION VOLTAGE
TO INDICATOR
FIXED
OSCILLATOR
PULSE
STRETCHER
AUDIO
AMPLIFIER
AUDIO
OUTPUT
AUDIO OUTPUT
AGC
AMPLIFIER
AGC
DETECTOR
AGC ON-OFF
RELAY
SWEEP
OSCILLATOR
SWEEP
DISCRIMINATOR
SWEEP
REVERSAL
RELAY
HORIZONAL DEFLECTION
VOLTAGE TO INDICATOR

AT.381

Figure 12-3.—Mixer amplifier block diagram.

the tuning dial. A second type of spurious response also frequently occurs; it is caused by harmonics of the local oscillator. These harmonics beat with strong signals being received at frequencies other than that indicated by the dial, and produce the intermediate frequency with the result that the unwanted stations are heard in the output.

There is another type of spurious response, called pseudoimage frequency, which is a strong signal beating with the fundamental IF frequency. Since one of the primary functions of the receiver is to enable the operator to determine the frequency of an intercepted signal by means of the dial reading, some device is needed to assist him in distinguishing true signals from spurious responses. For this purpose, wave-trap stubs or tunable filters are often used in conjunction with these receivers. The wave-trap stubs have a dial calibrated in frequency and can be switched into or out of the antenna lead-in. When the trap is in the circuit and tuned to the frequency of an incoming signal, the signal is filtered out and disappears from the output. By means of the calibration on the wave-trap, the operator can decide whether or not the signal frequency is actually that indicated by the dial reading at which he receives it. Generally, ECM receivers used in the fleet today have image rejection ratios sufficient to permit direct dial readings.

Automatic Search Receivers

Modern ECM receivers use automatic tuning. The receiver's tuning section is driven by an electric motor which tunes the receiver across its entire tuning range. The tuning is continuous; that is, when the upper end of the tuning range is reached, the motor automatically reverses and the receiver is tuned down to the lower end of the band where again the motor reverses and the receiver is tuned to the upper end of its range.

"Fully automatic" search receivers are similar in operation to those called automatic. However, there is one major difference. This difference is that fully automatic search receivers automatically stop tuning operations when a signal is detected. (NOTE: This is usually referred to as receiver lock-on.) The signal may then be observed and its frequency noted by the operator. When the operator completes his observation, a button is pushed (on the control box) and the tuning drive again starts through its tuning sequence from the point at which it was last locked.

PANORAMIC ADAPTERS

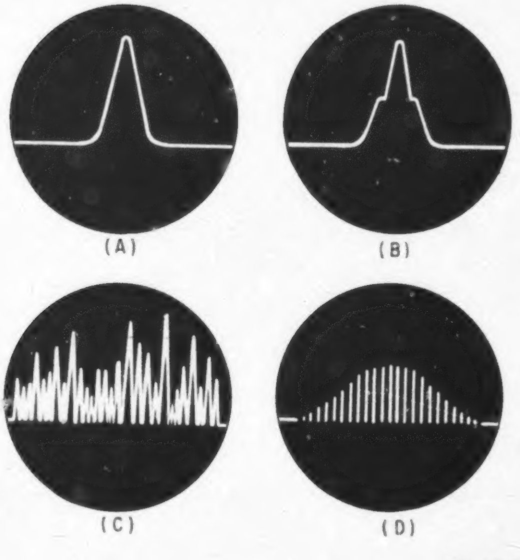
Panoramic adapters are specialized indicators. Used for monitoring a wide range of frequencies, they provide visual displays of the signals intercepted by the search receiver. The signal indications appear on the screen of a cathode-ray tube. The station to which the search receiver is tuned appears as an inverted-V deflection at the center of the screen; and signals above and below this frequency show similar deflections to the right or left of center, depending on their values. The amplitude of any deflection is determined by the strength of the corresponding signal, so that the panoramic screen provides a plot of signal intensity versus frequency. (Signal intensity is indicated on the vertical axis, and relative frequency is represented on the horizontal.)

In search operations, the panoramic adapter is used principally as a tuning aid since the signals from many stations are indicated simultaneously. It can also be used to determine the types of modulation of intercepted signals and for observing the effects of the search aircraft's own jamming emissions.

Interpretation of Patterns

Since a comparatively large number of signals may be observed simultaneously on the screen of the panoramic adapter, the instrument has great value in detecting enemy transmissions. Furthermore, the experienced operator can obtain additional information concerning the nature of the transmissions by inspection of the patterns. The oscillograms produced by several types of signals are shown in figure 12-4.

A constant carrier appears as a deflection with fixed height as shown in (A) of figure 12-4. Amplitude-modulated carriers appear as deflections which vary in height. If the modulating frequency is high, the sideband frequencies appear separately, causing pips on either side of



AT. 382

Figure 12-4.—Panoramic adapter patterns.

the carrier deflection. Modulation with a single audio tone produces the pattern shown in (B) of the figure. A frequency-modulated carrier appears to wobble to the side. When the carrier is frequency modulated by voice or music, the appearance is a number of deflections which spread across a variable band as in (C). Pulse modulation gives the pattern shown in (D) when the pulse repetition frequency is considerably greater than the rate of sweep of the indicator beam.

A CW signal appears and disappears with the keying of the transmitter. Two signals which are near enough in frequency to produce an audible beat note appear on the screen as a single carrier which varies in amplitude at the beat frequency. Noise voltages which vary regularly produce deflections which move across the screen in either direction, the motion being caused by the fact that the noise pulses are not synchronized with the panoramic sweep. Noise and interference, such as static bursts which are not periodic, produce irregular deflections and flashes along the length of the screen.

If image reception takes place in the associated receiver, the image signal has the same sort of appearance as the true signal. However, when the receiver tuning dial is rotated, the image pip moves in the direction opposite to that of the true signal deflection.

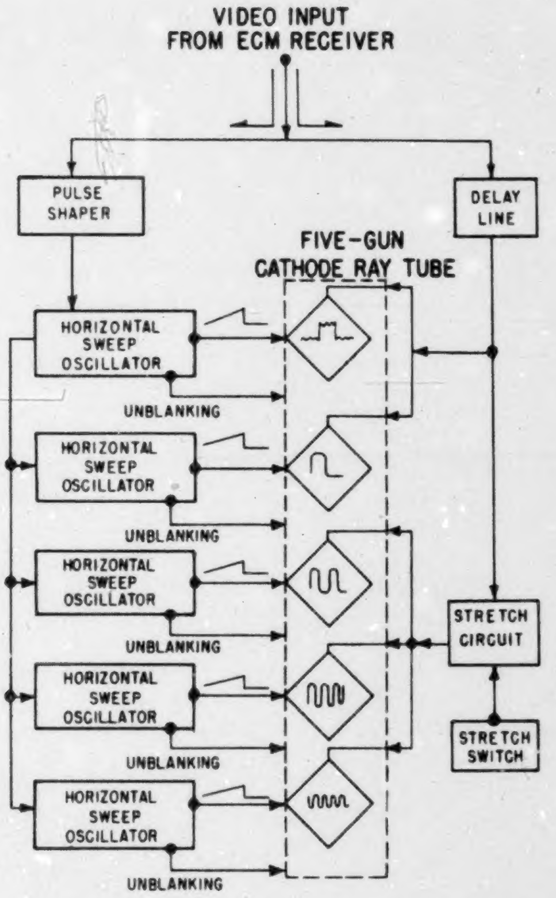
PULSE ANALYZERS

Pulse analyzers are used in ECM operations for measurement of the pulse repetition frequencies and pulse widths of radar signals detected by search receivers. The analyzer can also supply information concerning lobe switching, rotation rates, and beam widths of radar transmissions. In many pulse analyzers, the data are presented visually by means of cathode-ray tubes, although in some the pulse width and PRF values are indicated on meters. An example of the type using a cathode-ray tube as an indicator is shown in block diagram form in figure 12-5. The equipment shown is a synchroscope. (A synchroscope differs from an oscilloscope in that an input signal must be used to trigger the sweep. In actual practice this signal results from the interception of an enemy transmission.)

This analyzer's cathode-ray tube is unique in that it contains five separate electron guns within one glass envelope. The horizontal beam of each electron gun sweeps at a different frequency. Therefore, the signal that appears is shown on five different time bases. Various scales are engraved on the cursor so that desirable readings may be obtained. The two top traces show wide pulses so that pulse width may be measured. The three bottom traces indicate pulse repetition frequency.

The pulse from the search receiver follows two paths after it is fed into the pulse analyzer. One path leads to a pulse shaper which produces pulses having the same width and repetition frequency as the received video signal, as well as constant amplitude and rise time. The shaper output starts the horizontal sweeping action that unblanks each scope.

The other path is through a delay line to the vertical plates of the five guns in the CRT. This delayed signal is the deflecting voltage which produces a deflection of each time base so that


VIDEO INPUT
FROM ECM RECEIVER
PULSE SHAPER
DELAY LINE
FIVE-GUN
CATHODE RAY TUBE
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
STRETCH CIRCUIT
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
STRETCH SWITCH
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING

AT: 383

Figure 12-5.–Block diagram of a pulse analyzer.

signal characteristics are indicated. The delay is for a very short period of time. This insures that the leading edge of the pulse will be presented on the scope. In the last three electron guns, the horizontal sweep frequency is sometimes so low (slow sweep) compared to the signal frequency that the signal does not appear on the CRT. (Signal pulses appear but are too narrow to be seen.) In this case a stretching circuit can be switched in. The stretching circuit broadens, or stretches, the signal enough so that it shows on the scope.

When lobe switching is used by the enemy, the pulse width pattern appears as shown in figure 12-6. Because of lobe switching, the trace is not steady but appears to jump up and down. Although figure 12-6 shows a lobe-switching pattern on only one line, in actual practice the pattern would appear on all five lines of the CRT.

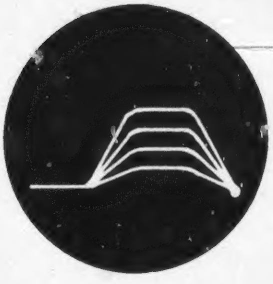
Cathode-ray oscilloscopes and audio oscillators are sometimes used to measure the repetition frequencies of radar pulses when a pulse analyzer is not available. The pulse repetition frequency is determined from the patterns which result from application of the received signal to the vertical deflection plates of the scope while sweeping the beam horizontally with the output of the calibrated audio oscillator.

The information derived with these various types of search equipment consists of the characteristics of the enemy signals. These properties form the basis for estimating the capabilities and weaknesses of the electronic installations and for devising effective jamming techniques to be used against them.

DIRECTION FINDERS

One of the essential things to learn about any radar or radio station operated by the enemy is its exact location. In search intercept flights this information can be obtained by the use of airborne ECM direction finders which have been developed for this particular purpose. The enemy transmitter reveals its location as long as it is sending out radio waves; but the problem of analyzing the emissions is complicated by the fact that the enemy may choose either vertical or horizontal polarization. Consequently, the direction finder must be capable of receiving either type of transmission.

In ECM direction finders designed for higher



AT.384

Figure 12-6.—Pulse width pattern obtained from lobe switching.

frequencies, typical equipments employ continuously rotating antennas which are highly directional. Signals received are displayed on a cathode-ray indicator on which is presented a polar diagram of reception obtained throughout 360° of rotation of the antenna. The pattern contains a major lobe which indicates the relative bearing of the station whose signals are displayed.

To locate a particular transmitter, the operator makes several readings of its relative bearing by means of the direction finder display. Each of these readings is called a "cut." With each cut, the operator records the time and the compass heading of the aircraft. This information is given to the navigator, who can determine, from the track of the flight, the exact location of the aircraft corresponding to each direction-finding cut. The track of the aircraft is then drawn on a chart and along it is marked the position at which each cut was made. Through each position a line is drawn, which makes an angle with the track equal to the recorded value of the relative bearing for that point. The intersection of the lines on the chart indicates the position of the enemy transmitter.

The direction finder display can also be used to learn the types of modulation of intercepted signals, to estimate pulse widths and repetition rates, and to determine the polarization of radar antennas.

Indicator Patterns

The cathode-ray screen of ECM direction finders employing visual displays shows the operator a polar graph on which the strength of received signals is plotted against relative bearing. To form the patterns, signals are received by the rotating antennas which are synchronized with the sweep of the cathode-ray beam of the indicator tube. Signals are received from a very small sector at any one time and are amplified and detected in the search receiver. Video pulses from the receiver are applied to the direction finder for further amplification. When they are applied to the indicator tube, they produce patterns similar to those shown in figure 12-7.

With each video pulse the electron beam in the CRT is deflected outward from the center of the screen; thus the length of the trace indicates the relative signal strength. The angular direction of each trace line represents the direction in which the antenna is pointing when the corresponding signal is received. The indicated bearing can be either relative or true, depending on the type of direction finder being used.

To read the relative bearing of a station when its signal is displayed, the operator uses a movable mask on which is inscribed an arrow; the mask is fitted over the indicator screen. The operator rotates the mask until the arrow bisects the major lobe of the pattern and then reads the relative bearing on a graduated scale surrounding the face of the indicator tube. In an indicator that reads true bearing, the azimuth scale is automatically rotated around the outer rim of the CRT.

SIGNAL CHARACTERISTICS.—Signal characteristics which create a distinctive pattern on the CRT are radar PRF, relative signal amplitude, modulation characteristics, and polarization. The best way to gain skill in interpreting the great variety of patterns that may possibly appear on the CRT is by observing known scope patterns (characteristics). (Refer to figure 12-7 for illustrations of representative scope patterns.) A certain amount of deduction will

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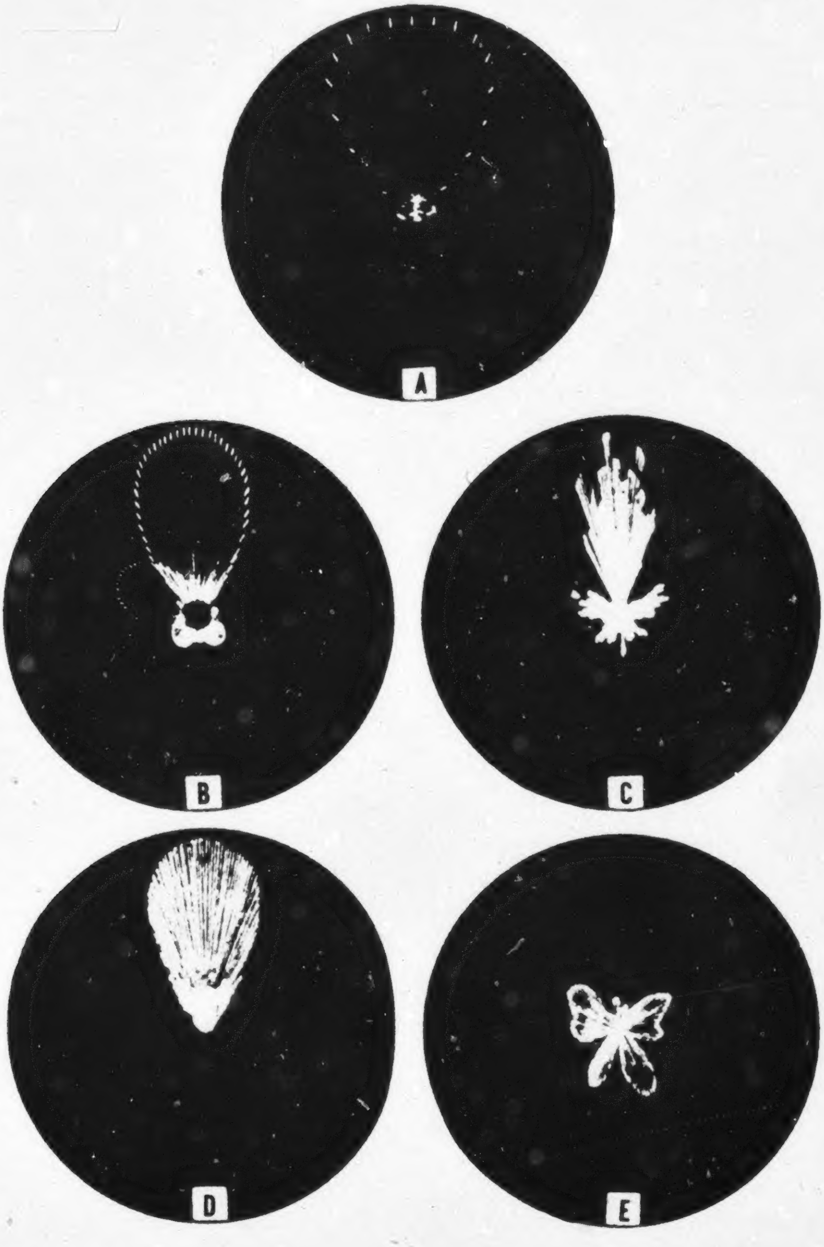


AT. 385

Figure 12-7.—Direction finder patterns.

inevitably be necessary because of the almost infinite number of possible pattern combinations.

The pattern shown in (A) of figure 12-7 results from the signals of a search radar located dead ahead of the aircraft. The PRF is a comparatively low value as indicated by the wide spacing of the traces. Bright tips appear at the trace ends which are characteristic of pulse-modulated waves such as those emitted by almost all radar transmitters. In (B) of the figure the indicator pattern is that resulting from simultaneous reception of two radars on different bearings.

In (C) of figure 12-7 the pulses are grouped in sets of different length, indicating a lobe-switching radar, possibly a fire control system. The pattern varies with the location of the search aircraft relative to the direction of the radar lobes. When the pulse groups form a smooth pattern with all traces of equal length, the indication is that the aircraft is being bracketed by the switching lobes of the radar and that the guns controlled by it are probably trained on the observer.

A signal from a communications transmitter employing voice modulation is shown in (D) of the figure. Communication signals are easily identified by the fact that they do not produce bright tips on the trace lines and the pattern has a fuzzy appearance. The pattern shown in (E) does not display a marked major lobe and indicates that the polarization of the direction finder antenna is different from that of the polarization of the received waves.

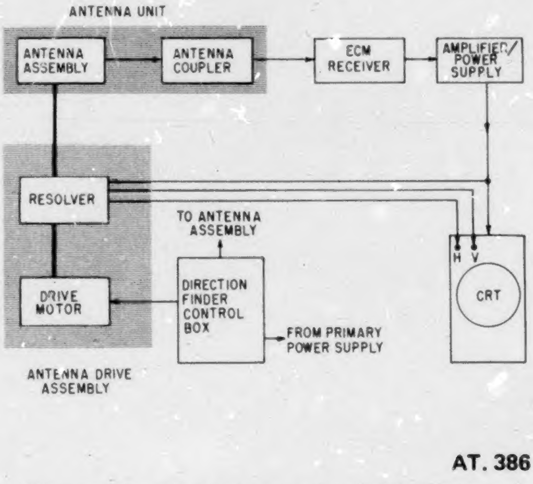
In radar patterns, the lengths of the bright tips on the trace lines provide a means of estimating the pulse width. With the unit whose display patterns are illustrated in (A) and (B) of figure 12-7, the ratio of the bright length to the total trace length expressed in percentage is approximately equal to the pulse width in microseconds. For example, if the bright tip is about 5 percent of the trace length, the pulse width is approximately 5 microseconds. The pulse repetition rate of the radar can be estimated roughly by the amount of spacing between the trace lines; however, the spacing is governed to some extent by the rate of rotation of the receiving antennas as well as by the PRF of the signals.

Equipment Components

An example of ECM direction-finding equipment which provides the type of display discussed above is illustrated in figure 12-8. This direction finder, when used with suitable radio or radar receivers, provides visual indications on a CRT. Such indication gives the true bearing of the received radio or radar signals. The direction indication is converted to true bearing by an azimuth scale which rotates around the outer rim of the CRT. Other information can be obtained from the CRT picture, such as approximate PRF, relative signal amplitude, modulation characteristics, and signal polarization.

The typical direction finder consists of five major units. These are an antenna unit, an antenna drive assembly, an amplifier/power supply unit, an azimuth indicator, and a control box. The type of receiver used was previously discussed. Its output video signal is supplied to the amplifier/power supply unit; this unit consists of a video amplifier and the power supply necessary to operate the direction finder.

The azimuth indicator unit contains a small CRT indicator. It has external adjustments for controlling the vertical and horizontal position-



AT. 386

Figure 12-8.—Block diagram of an ECM direction finder.

ing, and the focus and intensity. The indicator unit also has a torque unit and a gear train. These rotate the moving scale for the azimuth reading.

The control box is located at the operator's position. It provides means for selecting the proper antenna, varying the speed at which this antenna is rotating, switching the polarization of the antenna, varying the gain of the video amplifier, and turning the primary power off and on.

The antenna drive assembly has a d-c motor and a gear train to drive the resolver and the antenna. The video signal from the intercept receiver is amplified and then passed through the resolver which is geared to the antenna drive shaft. This resolver voltage is then delivered to the plates of the CRT. It impresses on the tube a signal which is a radius vector rotating about the center of the CRT. The rate of rotation is the same speed as the antenna's rotation.

The combined function of all of the units that make up the direction finder is to produce a CRT pattern of the received radio or radar signal. This pattern is produced in such a manner as to indicate the direction from which the signal is being received and then to convert that direction indication into a true bearing by means of the rotating azimuth scale.

ANTENNAS

The antenna assembly is an essential unit of an ECM installation. Ideally there would be two directional antennas for each frequency range, one polarized vertically and the other polarized horizontally. From the standpoint of space and weight this is impractical for aircraft installations. Aircraft ECM antennas are constructed so that they cover a broad band of frequencies and possess different polarization characteristics. Also, more than one antenna is mounted on the same antenna base. In many of the units, the assembly includes built-in impedance-matching sections.

Direction Finding Antennas

Figure 12-9 shows two views of a type of construction that is used in ECM direction finder antennas. Notice that there are three separate directional antennas. This practice makes possible the coverage of different frequency ranges. Also notice the different types of polarization used.

The three antennas are mounted on the [illegible] disk and may rotate through 360°. Only one antenna is active at a time as selected by a polarization switch on a remote control panel. This polarization switch selects the frequency band desired and the type of polarization used with the selected antenna. The feed of the parabolic reflector antenna is rotatable through a 90° angle to provide for reception of both vertically and horizontally polarized signals.

Search Antennas

Since enemy signals may appear over very wide ranges of frequency, the antennas used with ECM search receivers must necessarily be very broad in frequency response. To insure this, the antennas are made thick and stubby in structure so that the inductance value is low. As a result, the antenna stores very small amounts of energy and has a low Q with the broad frequency response which is characteristic of all low-Q circuits.

A type of ECM antenna used with airborne search receivers is shown in figure 12-10.

The stub antenna consists of a wooden mast about 22.5 inches in length which is covered with a thick metal plating. The plated area in a typical installation is connected to a receptacle for attachment to a 50-ohm coaxial cable.

Antenna Pods

Many types of aircraft employ pods which house ECM antennas and equipment. These pods may be installed on the wing tips, transported under the wing, or carried under the fuselage. A typical wing-tip pod installation is shown in figure 12-11.

ACTIVE ECM

Active ECM actions can be detected by the enemy and tend to prevent him from making effective use of his equipment. These actions consist of jamming, of deception, or a combination of both. The equipments used are of two

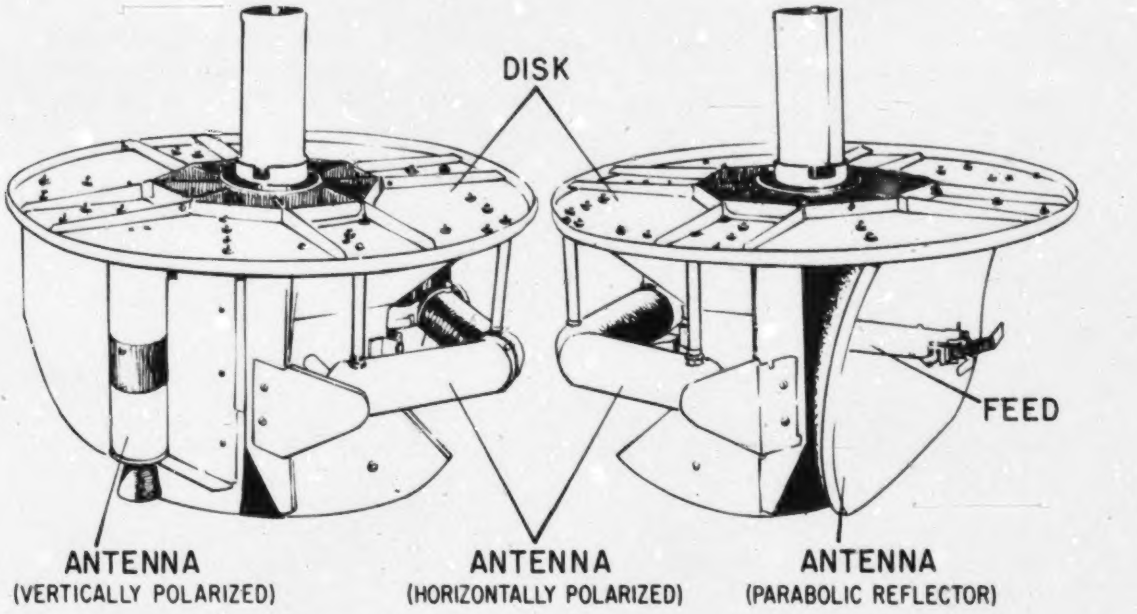

DISK
FEED
ANTENNA (VERTICALLY POLARIZED)
ANTENNA (HORIZONTALLY POLARIZED)
ANTENNA (PARABOLIC REFLECTOR)
AT. 387

Figure 12-9.—Direction finder antennas.

general types: electronic and nonelectronic. The electronic type includes jamming transmitters and pulse-repeating receivers. The jamming transmitters are used to produce interference with radar, navigation, and communications reception so that enemy receiver are subjected to obscuring and confusing radiations. Pulse-repeating devices are used for deception and are similar to radar beacons. They receive radar signals and respond with pulses which give the enemy false information concerning bearing or range.

Nonelectronic jamming is often accomplished by the use of strips of metallic foil released from aircraft (and sometimes fired in projectiles). The falling strips intercept radar waves and reradiate them, causing numerous false targets to appear on the enemy radar-scope so that the operator is unable to detect desirable targets and fire control radar is unable to see attacking aircraft.

Before active countermeasures can be undertaken, an extensive search, or intercept, campaign must be made to learn what types of electronic equipment are in active enemy use and the purposes for which they are employed. To gain this information, intercept flights are made in aircraft which carry special ECM equipment. With the equipment, the ECM operator tunes in signals from enemy units and measures their characteristics. He records the results in a log or acquires tape or film records which are later submitted to tactical officers for analysis and evaluation. The information gained is then used in planning active countermeasures, such as jamming, for directing control of radiation from friendly units, and for devising means of evading detection by the enemy equipments reported.

JAMMING TRANSMITTER

Electronic jammers are tunable radio transmitters used for producing interference. The

AT. 388

Figure 12-10.—Stub antenna.

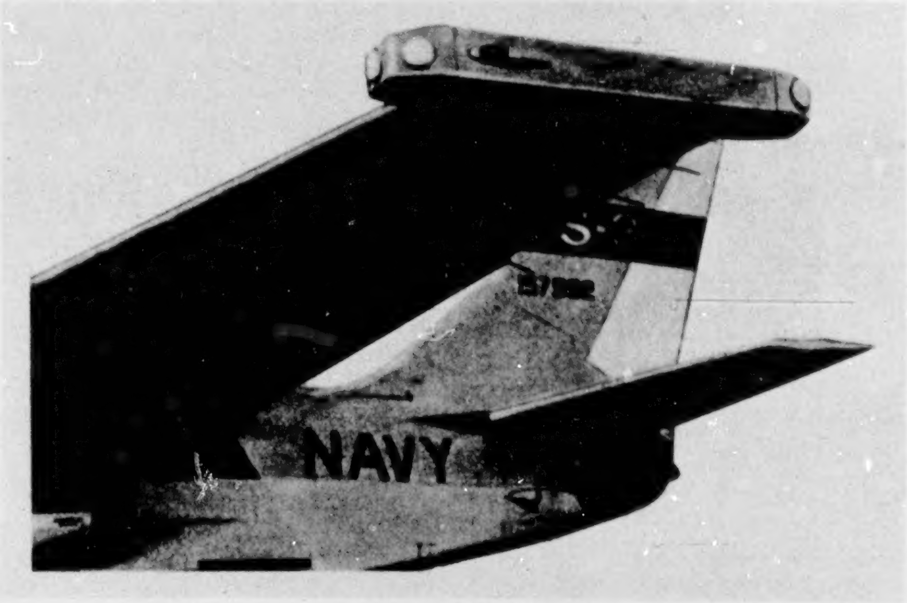
jammer radiates a carrier wave modulated with audio voltage suitable for drowning out reception or overloading enemy receivers. One of the most effective kinds of modulation for this purpose is random noise similar to the background disturbances heard in sensitive radio receivers when no station is being received. Noise makes a very desirable jamming signal since it distributes energy over a wide range of frequencies and cannot be filtered without loss of the desired signals. It is also difficult to recognize as manmade interference because of its similarity to atmospheric static impulses. A second type of jamming modulation is caused by sweeping the carrier over a wide range of frequencies at an audio rate. Another type consists of a repetition of several audio tones, three to five in number, which give rise to a wailing sound when received.

When operated against radar receivers, the EMC jammer works at a distinct advantage since the echoes returned from most targets are very weak, and the jamming signal usually competes only with low-level radar signals. An output power in the order of tens of watts can effectively overcome radar pulses originally emitted at a peak power in the order of kilowatts. As a result, low-powered transmitters can sometimes jam enemy radar reception at far greater than the maximum effective range of the radar. However, it is often necessary that the jamming signal be radiated continuously, and that the output power of the ECM transmitter be as great as the average power of the radar it can successfully jam. Because of these requirements, adequate cooling must be provided. This is usually accomplished by fans, but may be accomplished by other means such as a water jacket around the transmitter to remove the heat.

ECM transmitters are used in one or two ways, called spot jamming and barrage jamming. In the first of these, the operator tunes the jammer to the exact frequency of the receiver to be victimized by first tuning in the enemy signal with a search receiver. He then adjusts the output of the transmitter until the two signals coincide in frequency. Tuning for spot jamming is usually done in flight. Barrage jamming is accomplished by using a number of transmitters as in a formation of aircraft with each aircraft carrying at least one jamming transmitter. The units are pretuned to frequencies which differ by about 3 megahertz, a typical value of the bandwidth of an ECM transmitter. When all units are turned on, a wide range of frequencies is completely covered.

An example of an airborne jamming transmitter is shown in block diagram form in figure 12-12.

The typical countermeasures transmitting set is an airborne noise-modulated transmitting system. It is designed to jam enemy radar signals of any polarization over a wide frequency range. Such a transmitting set is suitable for use as a spot or sweep jammer, and for manual use with currently used ECM receivers. This set is a lightweight, airborne, noise-modulated jamming system which may be controlled either automatically or manually. The jamming transmitter is similar to the ECM receiver in that it covers a wide frequency range by using plug-in tuning heads. The noise source is generated by a special



AT. 44

Figure 12-11.—Wing-tip pod installation in the S-3A.

type tube. This noise is amplified through several stages of video amplification. This broad band of frequencies is fed to a pair of high-powered modulator tubes.

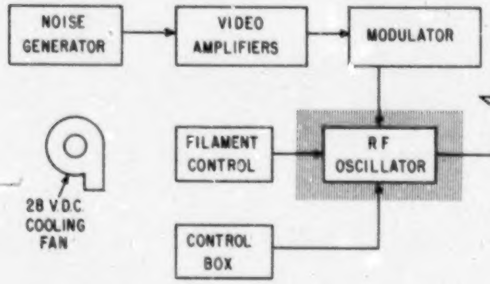
The RF oscillator stage is the stage that is replaced when different tuning heads are used. Each stage contains a mechanically tunable magnetron oscillator which is modulated by the generated noise signal.

The operator selects the mode of operation of the transmitter with the control box. Transmitter frequency may be changed manually by the operator turning a knob, or it will change automatically if set for automatic operation. A switch is incorporated on the control box which allows the operator to switch out the noise generator. When this is done the transmitter produces CW transmission; otherwise the output is modulated. The purpose of this switching arrangement is to produce another confusion factor for the enemy.

Automatic Jamming Equipment

Automatic jamming equipment consists of an automatic search receiver and an automatically tuned jamming transmitter.

The sequence of operation is as follows: The



AT. 389

Figure 12-12.–ECM jamming transmitter.

receiver searches a desired frequency range, and when a signal is detected, the receiver locks-on this signal. As the receiver locks-on, the transmitter is automatically tuned to the same frequency. When the transmitter tuning cycle is completed, the transmitter is then automatically keyed to begin jamming operation. Different types of jamming (pulse, noise, etc.) may be produced by the transmitter. The particular type of jamming to be used by the transmitter is preselected by the ECM operator.

It should also be noted that this system may be switched to manual operation. This enables the ECM operator to manually perform the sequence of steps in the operation of the system.

ANTIJAMMING CIRCUITS

An ECM development relating to active jamming is the antijamming circuit often installed in receivers, particularly those in radars. The antijamming device is designed to decrease the effectiveness of enemy jamming and hence is called a "counter-countermeasure." These circuits have two uses: They prevent interfering signals from overloading the receiver, and tend to separate the desired signals from the jamming signals. Typical antijamming circuits are simple inductance-resistance filters of the high-pass type. The effect of the circuit, which is usually associated with the video detector section in the receiver, is to pass the high frequencies present in the signal and suppress low-frequency components. As a result, the leading edges of pulses are accepted by the circuits following the filter and large blocks of jamming voltages are excluded from the video amplifier circuits.

NONELECTRONIC JAMMING

WINDOW and ROPE are code names for strips of aluminum foil used for nonelectronic jamming. The strips act as reflectors; and when released from aircraft, they return echoes to enemy radar receivers.

Window

Window (also called chaff) is tuned material. The strips of foil are cut to one-half wavelength of the radar signal to be reflected, and each strip acts as a resonant dipole antenna which intercepts and reradiates energy. The dipoles are packaged in cardboard folders which are either dropped manually or released by automatic window dispensing devices. Each package contains foil cut for a certain frequency so that a folder may contain from 50 to 200,000 dipoles, depending on the wavelength of the system for which it is prepared. Typical bundles contain several thousand strips, and weigh less than two ounces. When the package is released, it opens so that the dipoles scatter into the air and begin falling at the rate of about 400 feet per minute.

Skilled radar operators can distinguish between aircraft pips and a single window echo; for this reason, window is seldom dropped in isolated packages. Usually, a lead aircraft lays down a path consisting of many packages spaced at intervals of 1,000 feet or less. The aircraft which follow in the formation fly through the resulting clouds of reflectors, and enemy operators find it difficult to separate the single pip of an aircraft from the mass window echoes. Thus, the following aircraft are protected from radar-controlled antiaircraft fire and concealed from air search radars. On the radarscope, the dispensing aircraft appears as a pip which divides into two parts. The pulse representing the aircraft moves across the screen while additional echoes appear behind it and remain stationary. As the dipoles disperse in the air, the stationary pip grows into a shapeless mass in which the following aircraft are practically invisible. Aircraft must be inside the cloud of reflectors to be hidden; those behind but not within the cloud can be detected by radar waves which pass through the strips.

Window is often used in conjunction with electronic jamming transmitters to protect a formation of aircraft from radar-controlled gunfire.

Rope

Rope is similar to window in that it is a confusion reflector, but it differs from it in length and also in the fact that it is untuned. Strips of rope are aluminum ribbons about 400 feet in length and about one-half inch in width. The ribbons are used as nonresonant reflectors for jamming low-frequency radars and are also employed in regions where the enemy operates many units which differ considerably in frequency. The rope material is dispensed in the form of a roll, one end of which is attached either to a small paper parachute or to a square of cardboard. The rolls equipped with parachutes assume a vertical position while falling and reflect waves that are vertically polarized. Those attached to cardboard squares unwind and float downward in a horizontal position, thereby reflecting horizontally polarized radar pulses.

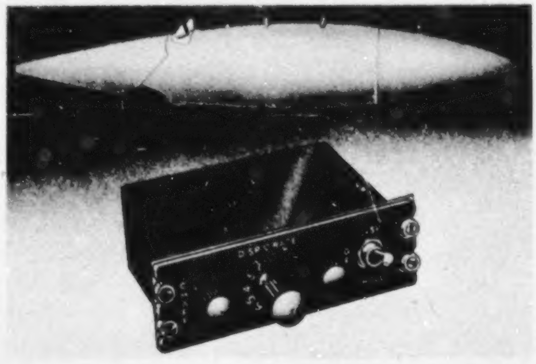
Although this technique is effective against normal pulse radar, it is relatively ineffective against MTI (Moving Target Indicator) radar.

Decoys

Decoys are small aircraft type vehicles, or missiles equipped with corner reflectors, chaff dispensers, or other devices to simulate a large aircraft, or a group of aircraft and so present erroneous targets. Disadvantages of this type of deception device include its expense, and because of size requirements, very few can be carried by an aircraft to be launched in a hostile area. Decoys may also be deployed by inflatable balloons, parchutes, or kites.

CHAFF DISPENSERS

Chaff dispensers together with the dispenser control (fig. 12-13) are designed for use with a variety of military aircraft. Their purpose is to carry and dispense packaged chaff material (window) for jamming and deceiving enemy radar equipment.

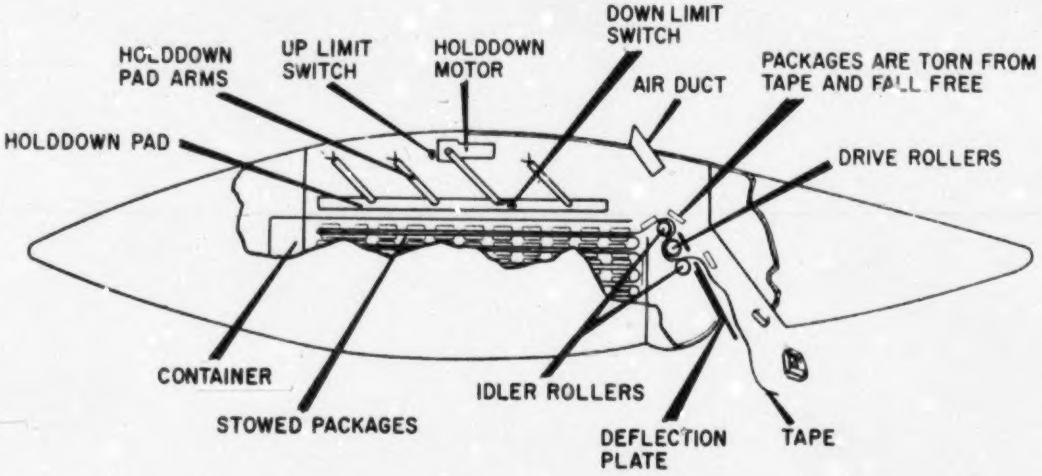


AT. 390

Figure 12-13.—Dispenser and control.

The chaff material is held firmly in place in the container by the package holddown assembly. (See fig. 12-14.) The holddown assembly is in the DOWN position (after loading) until ready to dispense the chaff material. To start the operation the operator moves the DISP-OFF-HOLD switch (fig. 12-13) from HOLD to the DISP position, energizing the holddown motor and raising the holddown pad until the pad actuates an up-limit switch (normally open) supplying power to the drive motor. The drive motor pulls the tape, which carries the chaff material aft over the idler rollers and into the airstream coming from two air ducts in the dispenser body. The airstream deflects the chaff material down and out of the opening in the aft underside of .the dispenser. A tape cutting feature is incorporated in the dispenser to prevent long streams of chaff tape fouling the packages or tail assembly of the carrying aircraft. An automatic motor disconnect switch is provided to automatically open the motor circuit when all the chaff packages have been dispensed.

The dispenser consists of three detachable sections which latch together to form a stream-



AT. 391

Figure 12-14.—Principles of operation (chaff dispenser).

lined fairing. The center section contains the chaff package container, package holddown mechanism, and dispenser drive mechanism. Some models include a tape cutting assembly incorporated into the drive assembly. The nose and tail sections streamline the unit and detach to facilitate loading and servicing. (See fig. 12-14.)

Dispenser Control

The dispenser control (fig. 12-13) is installed within the aircraft either on the cockpit panel or in some convenient location, and contains all necessary controls for the operation of the dispensing system. The control consists of a DISP-RATE selector, a DISP-OFF-HOLD switch, and two panel light assemblies (connected to the aircraft cockpit panel light circuit). The DISP-RATE selector consists of a double wafer, a ten-position switch, a knob, and a plastic dial.

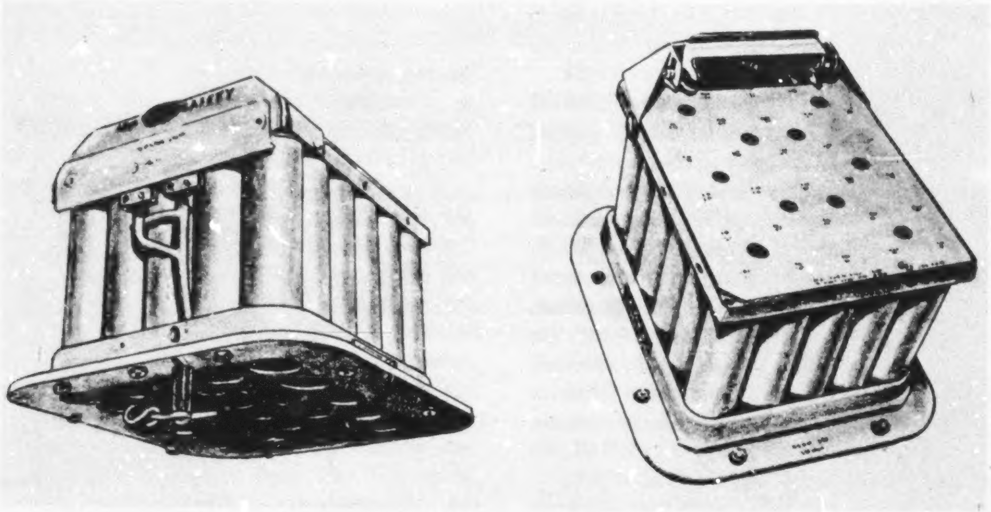
The DISP-OFF-HOLD control is a three-position toggle switch, spring loaded from HOLD to OFF positions. The DISP position controls the power to the dispensing mechanism, and the HOLD position actuates the package holddown mechanism within the dispenser.

Maintenance of the dispenser and the dispenser control and loading of the chaff materials within the dispenser are the responsibility of the Avionics personnel.

The dispenser is approximately 117 inches long and 18.4 inches in diameter at its thickest part. The weight when empty is 86 pounds as compared to 210 pounds when loaded. The dispenser is loaded on a bomb rack, and receives operating power from the aircraft's 28-volt d-c supply through the dispenser control.

Internally Mounted Dispensers

Figure 12-15 shows an internally mounted chaff dispenser. Two of these units are normally installed in one aircraft. Each dispenser unit consists of 30 discharge tubes joined together in parallel. One end of each tube is open and the other end is closed. The closed ends contain electrical contacts which operate an electrical initiator. The open ends are connected to a platform which serves as a mounting flange for the unit. The initiators serve as the propelling



AT. 392

Figure 12-15.—Chaff dispensers.

force to discharge the tubes' load through the open end into the atmosphere.

This system, which may be operated either manually or automatically, or both manually and automatically at the same time is controlled by the chaff control panel shown in figure 12-16. Manual dispenser operation is initiated with a chaff switch (B). The remainder of the system is comprised of a programmer (A), which is usually set (programmed) prior to each flight, and safety and sequencing switches located throughout the aircraft (fig. 12-17).

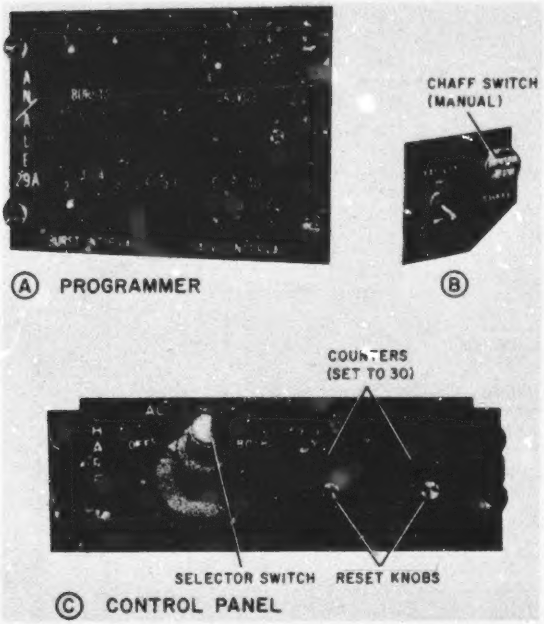
NOTE: Reference to figures 12-16 and 12-17 should be made at frequent intervals throughout the remainder of this discussion.

With the chaff dispensing set in a ready status, automatic operation may be initiated by momentarily depressing the automatic dispenser button in the center of the selector switch on the control panel (fig. 12-16 (C)). When the switch is depressed and released, automatic circuits in the programmer are actuated to supply firing pulses to the selected dispenser sequencing switch. The sequencing switches direct firing pulses to electrical initiators in the top of tubes in the dispensers (fig. 12-15).

During set operation, firing pulses will be sequenced to the dispenser selected, then switched automatically to the remaining dispenser when the first dispenser is empty. Firing pulses can be directed to either dispenser independently or both dispensers simultaneously as selected by the selector switch on the control panel.

The amount of chaff dispensed by the set is measured in bursts and salvos. The contents of one dispenser tube is a burst. The number of bursts selected on the programmer bursts switch (fig. 12-16) comprises a salvo. The amount of chaff dispensed during set operation and the interval between bursts and salvos is normally set before flight on the programmer.

Each decoy dispenser contains 30 tubes. As a firing pulse is routed through the sequencing switch to the initiator in each tube, a pulse also goes to a subtractive counter on the control panel. The counters, one for each dispenser, are set to indicate the number of loaded tubes installed in each dispenser. When a firing pulse goes to a dispenser tube, the counter for the dispenser containing the tube reflects one bundle fewer remaining in that dispenser. Each



AT. 46

Figure 12-16.—Chaff dispensing set controls.

counter must be reset with the knob below the counter when the dispensers are loaded by the technician.

ECM DESTRUCT SYSTEMS

An ECM destruct system is designed to prevent compromise of circuits in electronic countermeasure sets. When activated the destruct system will destroy internal circuits in predetermined equipment. (See figure 12-18.)

SYSTEM OPERATION

Destruct system operation is controlled by an ECM arming switch which is normally in the SAFE position while the aircraft is on the ground. Before any one of three actuation switches can initiate destruction operations the arming switch must be moved to ARMED.

With the system armed, system destruction may be initiated manually if the destruct switch on the control panel is moved to the DESTRUCT position. This action completes a circuit to the destruct igniter initiator which in turn directs power from the battery to the receiver and receiver-transmitter, and supplies a destruct enable signal to the wing station pods.

The seat destruct switch is closed automatically if the pilot ejects from the aircraft. If the system is armed when this switch closes, a circuit is completed to the destruct igniter initiator, and battery current is applied to the equipment to be destroyed. An enabling circuit also is completed and destruct capabilities are initiated in wing station pods.

Destruct circuits will also be energized in a similar manner if the system is armed and the aircraft encounters an impact of 60 g's or more. This impact switch is located inside the destruct igniter initiator.

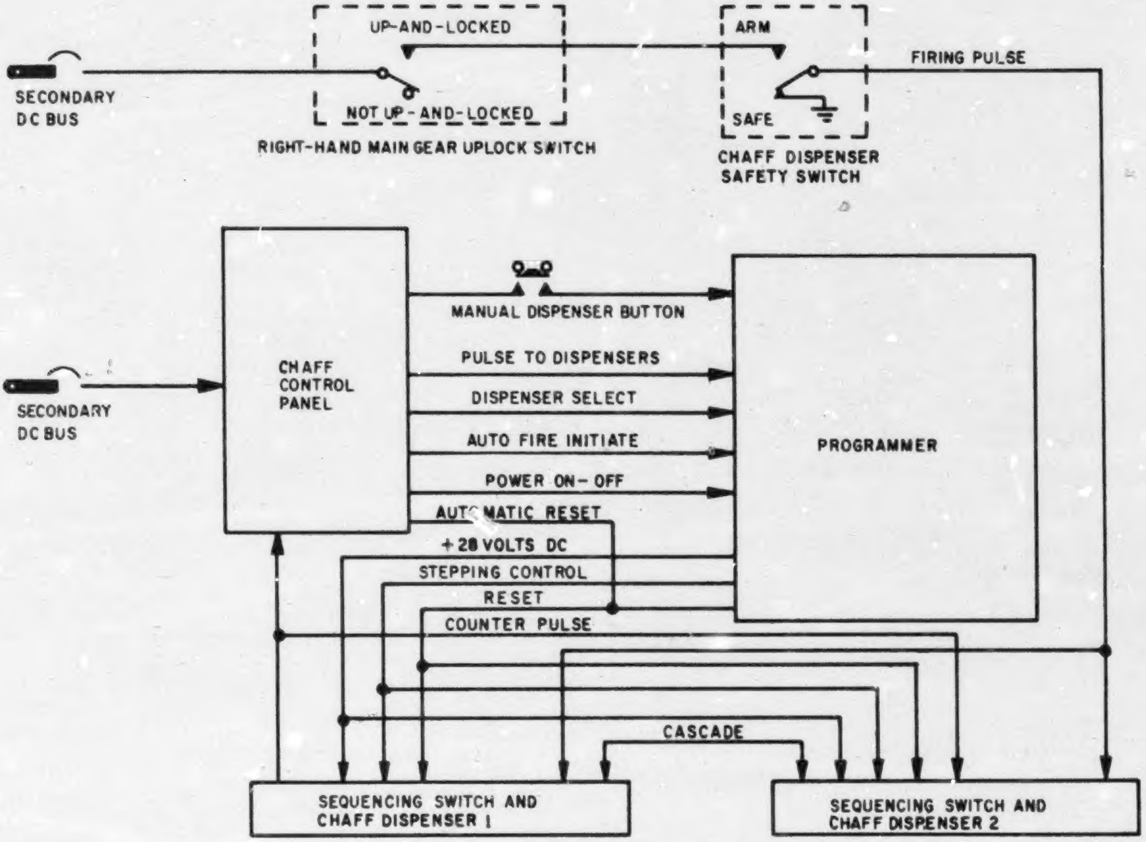
The destruct battery uses heating elements to maintain a predetermined minimum temperature within the battery. Heater current is regulated by a thermal switch inside the battery unit. This battery requires periodic replacement to assure that a maximum battery charge is maintained.

ECM SUPPORT EQUIPMENT

Most of the support equipment used in the maintenance of ECM equipment is common to many other types of electronic equipment. The support equipment that may be considered special ECM test equipment includes the RF signal generator(s) used to aline the ECM receivers, control group test sets, and chaff dispensing test sets. Due to its security classification, ECM test equipment contained in this chapter is limited in scope. Reference should be made to the appropriate manual for information on these equipments.

RF SIGNAL GENERATORS

Each generator used usually covers only one relatively small band of frequencies. Several generators are needed to maintain a complete set of ECM receivers. These RF generators produce various kinds of modulated RF signals. For example, continuous wave, modulated continuous wave, or pulse modulation may be selected. With tone modulation, various tone frequencies


UP-AND-LOCKED
NOT UP-AND-LOCKED
RIGHT-HAND MAIN GEAR UPLOCK SWITCH
SECONDARY DC BUS
ARM
SAFE
FIRING PULSE
CHAFF DISPENSER SAFETY SWITCH
CHAFF CONTROL PANEL
SECONDARY DC BUS
MANUAL DISPENSER BUTTON
PULSE TO DISPENSERS
DISPENSER SELECT
AUTO FIRE INITIATE
POWER ON-OFF
AUTOMATIC RESET
+28 VOLTS DC
STEPPING CONTROL
RESET
COUNTER PULSE
PROGRAMMER
CASCADE
SEQUENCING SWITCH AND CHAFF DISPENSER 1
SEQUENCING SWITCH AND CHAFF DISPENSER 2

AT. 47

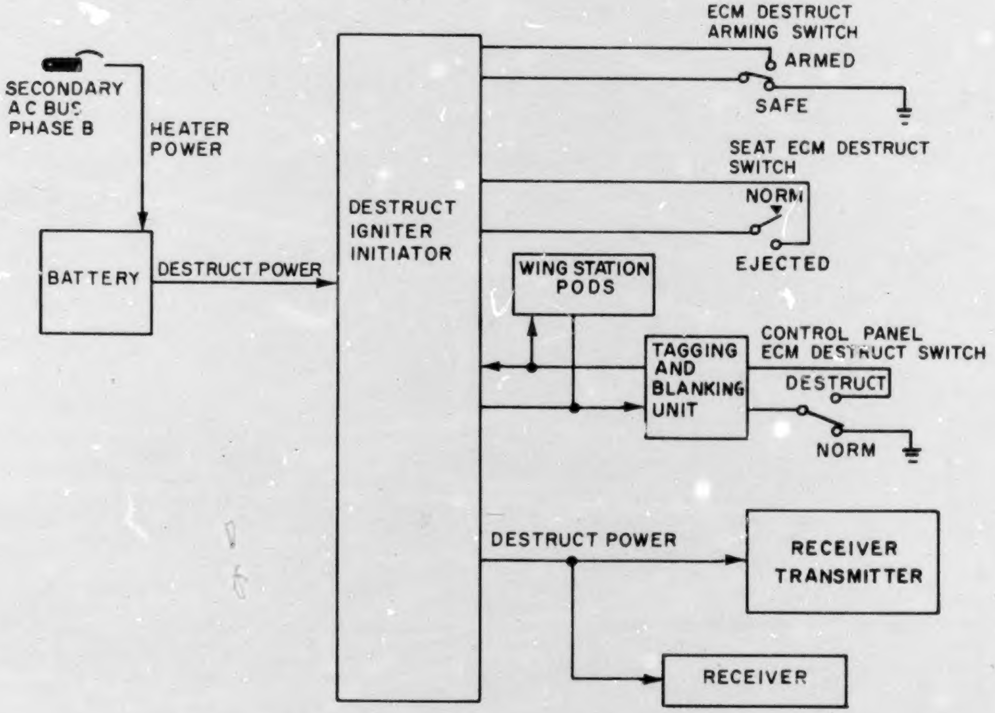
Figure 12-17.—Dispensing set block diagram.

may be selected. With the pulse modulation selected, various pulse widths and different pulse repetition frequencies may be used.

CONTROL GROUP TEST SET AN/ALM-75

The AN/ALM-75 test set (fig. 12-19) is a self contained unit used for checkout of the AN/ALA-29 and AN/ALA-31 countermeasure control groups at the organizational maintenance level. It basically consists of Test Set TS-2648/ALM-75 and Control-Monitor C-7626/ALM-75 plus various interconnecting cables. The TS-2648 generates test signals, receives reply signals from a unit under test, and processes the replies to determine whether the unit under test is operating correctly. The C-7626 controls test operation and visually presents test results and other test information on indicator lamp displays.

During a test operation, the test set simulates the characteristic impedance of the selected system while stimulating the unit under test with the proper signals for the selected test. The unit under test responds by generating control signals which are sent back to the test set. Logic circuits in the test set determine the validity of


ECM DESTRUCT ARMING SWITCH
ARMED
SAFE
SECONDARY A C BUS PHASE B
HEATER POWER
SEAT ECM DESTRUCT SWITCH
NORM
DESTRUCT IGNITER INITIATOR
BATTERY
DESTRUCT POWER
WING STATION PODS
EJECTED
CONTROL PANEL ECM DESTRUCT SWITCH
TAGGING AND BLANKING UNIT
DESTRUCT
NORM
DESTRUCT POWER
RECEIVER TRANSMITTER
RECEIVER

AT. 48

Figure 12-18.—A representative ECM destruct system block diagram.

the received signals, and provide the operator with a GO or NO-GO display. Since the test set is connected directly to a weapon system connector on the aircraft, the aircraft wiring is also checked at the same time that the control group is being tested.

CHAFF DISPENSER TEST SET AN/ALM-63

The Chaff Dispenser Test Set AN/ALM-63 (fig. 12-20) is used to test the Countermeasure Chaff Dispensing Set AN/ALE-29, either on the aircraft or in a bench test (shop) situation.

During flight-line testing (organizational) the TS-2495 monitors the circuit functions of the controls and wiring to insure that RF voltages are not present when the final cable connections are made with the dispenser assemblies. The TS-2496 monitors the circuit functions of the dispenser to insure that the individual circuits do not carry signal potentials and that they are properly shunted to ground. If any of the initiator circuits show a signal during the RF voltage test, a dangerous condition exists which could cause an initiator to fire at the moment of dispenser hookup or at the time of a nearby RF transmission. Therefore, the technician must troubleshoot this condition immediately.

As with any testing situation the technician should always consult the appropriate maintenance instructions manual on the particular equipment being maintained prior to the actual test procedure. Each manual contains a comprehensive testing procedure associated with the respective equipment to be tested.

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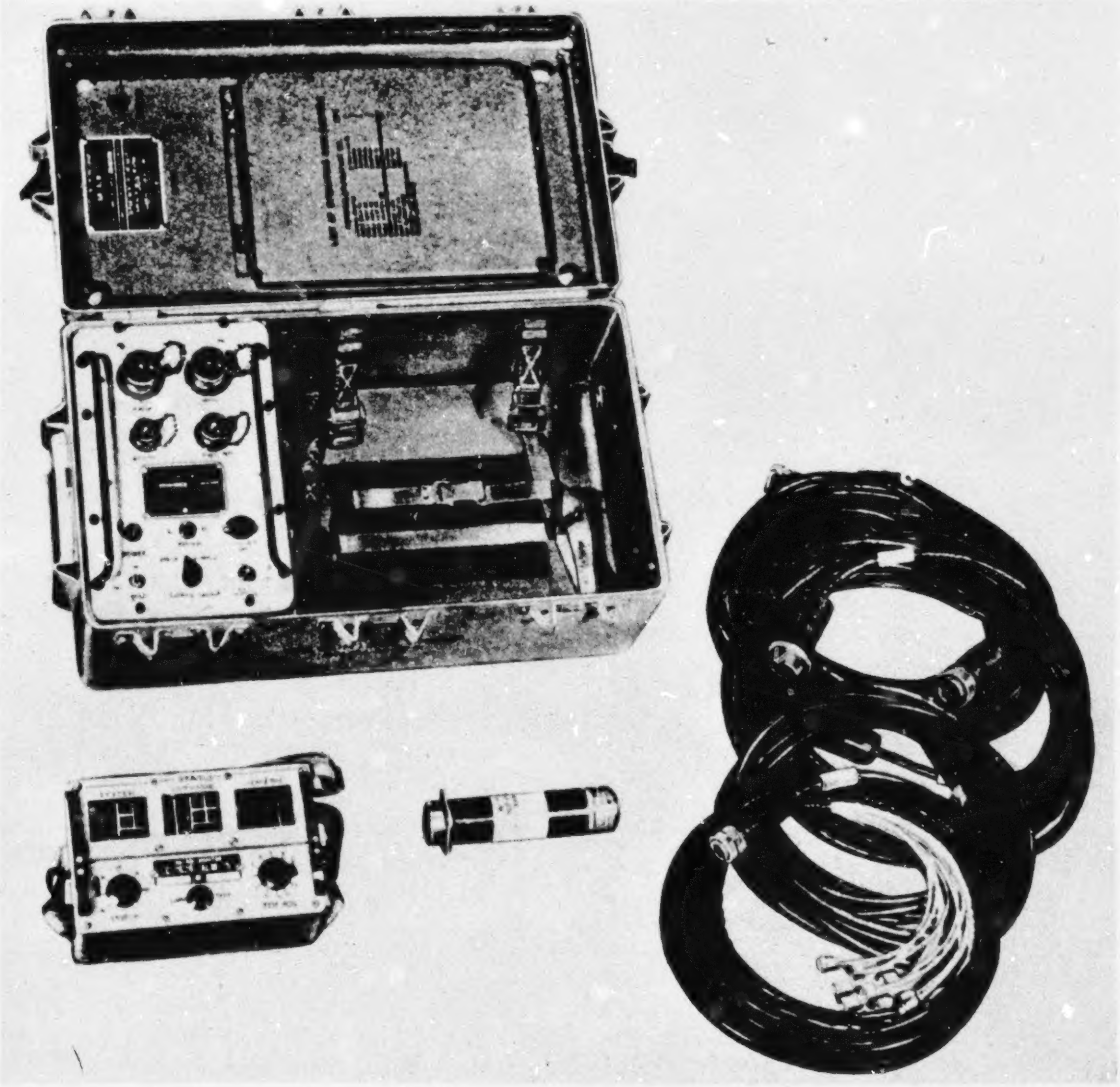
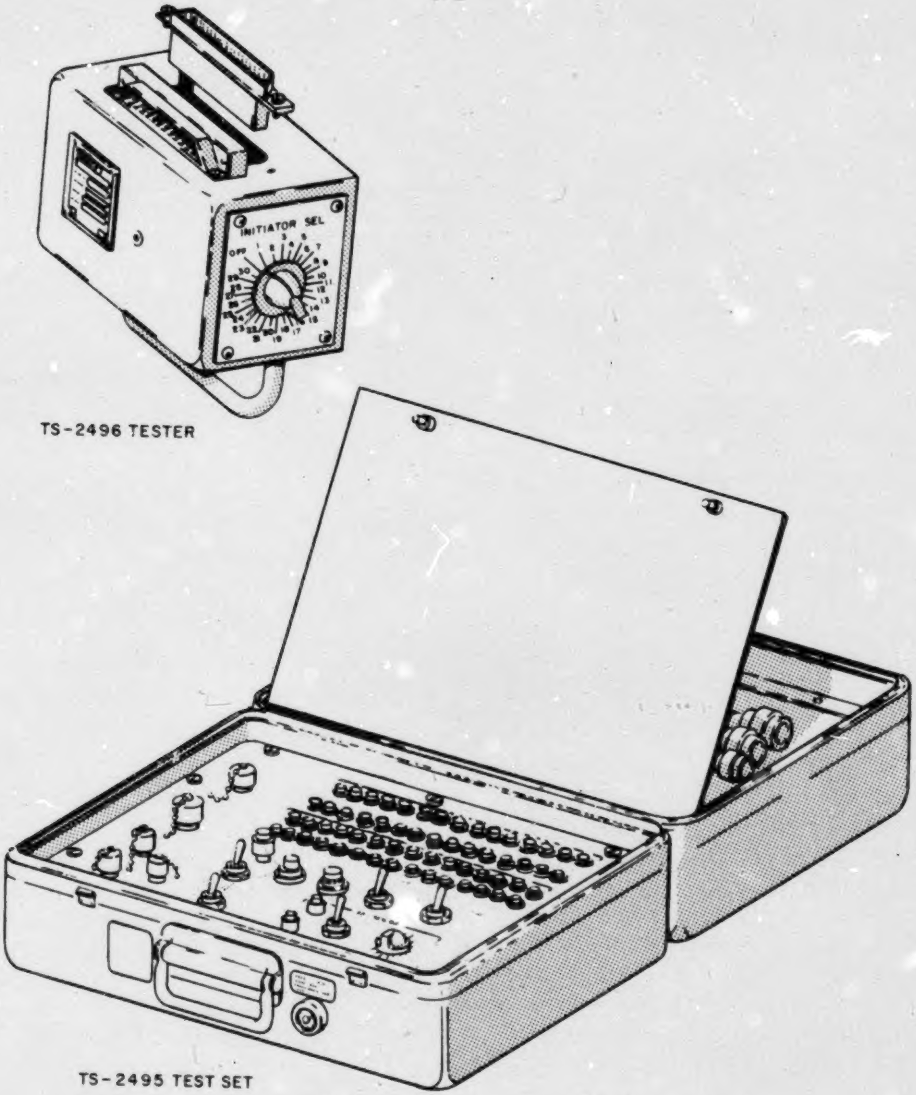


AT. 50

Figure 12-19.—Control Group Test Set AN/ALM-75.


INITIATOR SEL
OFF
TS-2496 TESTER
TS-2495 TEST SET

AT. 51

Figure 12-20.–Chaff Dispenser Test Set AN/ALM-63.

CHAPTER 13

SECURITY

A study of history indicates that most wars are carefully planned long before the first shot is fired. During this so-called peaceful period, nations are engaged in the collection and evaluation of all forms of intelligence material from potential enemies.

In peacetime, people tend to relax; security is sometimes ignored. This tendency makes it easier for a potential enemy to gather information concerning our capabilities and intentions.

The term security is defined as "A protected condition of classified information which prevents unauthorized persons from obtaining information of direct or indirect military value." This condition results from the establishment and maintenance of protective measures which insure a state of inviolability from hostile acts or influence.

A simple security principle is used within the Department of Defense. Only personnel with the proper clearance and "need to know" are permitted possession or knowledge of classified information. The responsibility of determining whether a person's duties involved a "need to know," or if that person is authorized to receive classified material, rests upon the possessor of the material and not upon the prospective recipient.

CLASSIFICATION CATEGORIES

Official information which requires protection in the interest of national defense is classified under one of three categories: Top Secret, Secret, and Confidential. No information may be withheld or classified, if otherwise releasable, simply because such information might reveal an error, inefficiency, or might be embarrassing.

TOP SECRET

Use of the classification Top Secret is limited to defense information or material which requires the highest degree of protection. Top Secret is applied only to information or material, the unauthorized disclosure of which could result in EXCEPTIONALLY GRAVE DAMAGE to the nation, and could:

1. Lead to a break in diplomatic relations, armed attack on the United States or its allies, or a war.
2. Compromise military plans or scientific or technological developments vital to the national defense.

SECRET

Use of the classification Secret is limited to defense information or material, the unauthorized disclosure of which could result in SERIOUS DAMAGE to the nation, and could:

1. Jeopardize the international relations of the United States.
2. Endanger the effectiveness of a program or policy vital to the national defense.
3. Compromise important military or defense plans, or scientific or technological developments important to national defense.
4. Reveal important intelligence operations.

CONFIDENTIAL

Use of the classification Confidential is limited to defense information or material, the unauthorized disclosure of which could result in DAMAGE to the nation.

CUSTODY

STORAGE

Commanding officers are directly responsible for safeguarding all classified material and for establishing measures for the inspection of safe-storage containers and areas where classified material is kept to insure compliance with security regulations. The term Commanding Officer is intended to include "competent authority," "commander," "officer in charge," "naval representative," "director," "inspector," and any other title assigned to an individual, military or civilian, who, through position or status, is qualified to assume responsibility and render decisions.

Numerical Evaluation System

A system has been developed for the purpose of providing a uniform guide for establishing security protection of classified material in storage that is equal in value to the classification of that material. This system does not guarantee protection, nor does it attempt to meet every conceivable situation, but with a commonsense approach it is possible to obtain a satisfactory degree of security with a minimum of sacrifice in operating efficiency.

This system is called the Numerical Evaluation System. It contains two elements: (1) a Table of Numerical Equivalents which assigns numerical values for various types of storage areas, containers, and guarding and alarm systems which by themselves or together may be used in the security program for the protection of classified material; and (2) an Evaluation Graph which establishes, in the form of numerical values, minimum levels of security required for protection of classified material based on its classification, the quantity, and the scope of the material.

Combinations

In keeping with the Navy's security principle of "need to know," it is essential that combinations to locks of classified containers be known only to those who actually control the classified material. Also, a record of combinations shall be sealed in an envelope and kept on file by the person designated by the Commanding Officer.

When selecting combinations, personal data such as birth dates and serial numbers, multiples of 5, and simple ascending or descending arithmetic series should be avoided. A combination should never be used for more than one container in any one component.

When securing dial combination locks, the dial should be rotated at least four complete turns in the same direction. The drawers of safes and cabinets should be checked to assure they are held firmly in the locked position.

CUSTODIANS

Custodians of classified material are responsible for providing protection and accountability for that material at all times, and for locking classified material in appropriate security equipment whenever the material is not in use or under direct surveillance of authorized persons.

Classified material should not be removed from working areas for the purpose of working on such material during off-duty hours, or for any other purpose that involves personal convenience. However, when classified material is removed from the physical confines of the command, as when it is taken to a conference or other local areas, a complete list shall be prepared by the individual removing the material. This list should be filed in accordance with local directives.

Emergency Planning

Plans must be developed by each command for the protection, removal, or destruction of classified material in case of natural disaster, civil disturbance, or enemy action. Such plans shall establish detailed procedures and responsibilities for the protection of classified material so that it does not fall into unauthorized hands in the event of an emergency, and shall indicate what material is to be guarded, removed, or destroyed. An adequate emergency plan provides for: guarding the material; removing the classified material from the area; complete destruction of the classified material on a phased, priority basis; or any combination of these actions. However, reducing the amount of classified material on hand, and maintaining only current and necessary material, can be the most effective step toward planning for an emergency situation.

Emergency plans should provide for the protection of classified information in a manner which will minimize the risks of loss of life or injury to personnel.

Accountability

Except for publications containing a distribution list by copy number, all copies of Top Secret documents must be serially numbered at the time of origination, in the following manner: "Copy No.__of__copies."

Top Secret documents shall contain a list of effective pages; this list should include a Record of Page Checks. When this is impractical, as in correspondence or messages, the pages shall be numbered as follows: "Page__of__pages."

Commanding officers establish administrative procedures for recording all Secret material originated and received, and maintain a receipting system for all Secret material distributed or routed to activities outside their commands. As a general rule, Secret materials are also serially numbered.

Commanding officers also provide accountability for all Confidentail materials originated or received by their commands.

ACCESS AND DISSEMINATION

Eligibility Standards

Personnel whose work requires access to classified material must be granted an appropriate clearance. The standards for the various levels of clearances are different, but they all follow a basic format for both civilian and military personnel. Essentially, the standards are that no person shall be permitted knowledge of, possession of, or access to classified material solely by virtue of rank, position, or security clearance. Clearance serves to indicate that the persons concerned are eligible for access to classified material should their official duties so require, and no person will be granted a security clearance unless it has been determined that the clearance is in keeping with the interests of national security.

Any person authorized access to classified information must be considered to be loyal, of good character, of good integrity, trustworthy, and of such habits and associations as to indicate good discretion or judgement in the handling of classified information.

The ultimate determination of whether the granting of a clearance is in keeping with the interests of national security must be an overall determination based on all available information. Personal data, both past and present, that are investigated and considered before granting a clearance include: Any criminal, infamous, dishonest, or notoriously disgraceful conduct; habitual excessive use of intoxicants; drug abuse; sexual perversion; and any excessive indebtedness, recurring financial difficulties, unexplained affluence, or repetitive absences without leave which furnish reason to believe that the individual may act contrary to the best interests of national security.

Security Clearance

A personnel security clearance requires an administrative investigation by competent authority and certifies that the person is eligible for access to classified material of the same or lower category as the clearance being granted. Security clearances are of two types:

1. Final clearance—one granted upon completion of the required investigation.
2. Interim clearance—a temporary eligibility for access to classified information based on a lesser investigative requirement.

An interim clearance shall be issued only when it is clearly established that the delay while waiting for the completion of the investigation required for a final clearance would be harmful to the national interest. When interim clearance procedures are used, the investigation required for a final clearance must be initiated, and a final clearance shall be executed upon the satisfactory completion of the investigation, unless such clearance is no longer required.

Requirements for Security Clearance

The clearance requirements listed below are solely for military personnel.

TOP SECRET.–The investigative requirements for access to Top Secret material are:

1. Final clearance–a Background Investigation plus a records check by the issuing command; however, any person having a Top Secret clearance based on a National Agency Check prior to 1 Jan. 1973 with 15 years of continuous active duty does not require a Background Investigation.
2. Interim clearance–a satisfactory completion of a National Agency Check.

SECRET.–For access to Secret material, a final clearance requires a National Agency Check plus a records check by the command. An interim clearance cannot be issued to personnel (1) with less than two consecutive years of active duty, (2) and until a name check has been made with the Defense Central Index of Investigations and with BuPers files.

CONFIDENTIAL.–No formal investigation is required for the issue of a Confidential clearance, provided a records check by the issuing command notes no derogatory information. An interim clearance for Confidential is not authorized.

TYPES OF PERSONNEL SECURITY INVESTIGATIONS

Personnel security investigations are of the following types:

1. National Agency Check.
    a. National Agency Check and Inquiry.
2. Background Investigation.

NATIONAL AGENCY CHECK

A National Agency Check consists of a check with various Federal agencies for pertinent facts having a bearing on the loyalty and trustworthiness of the individual. The initial NAC conducted on inductees and first term enlistees does not include detailed technical fingerprint search, and is referred to as an ENT-NAC.

A National Agency Check and Inquiry (NACI) consists of a National Agency Check (described above) and Written Inquiries sent to law enforcement agencies, former employers, references, schools attended, etc., for pertinent facts which may have a bearing on the individual's suitability for Federal employment.

BACKGROUND INVESTIGATION

A Background Investigation which is conducted for clearance purposes is designed to develop information as to whether the access to classified information by the person being investigated is clearly consistent with the interest of national security. It shall make inquiry into the pertinent facts bearing on the loyalty and trustworthiness of the individual. It normally covers the most recent 15 years of his life, or from the date of his 18th birthday, whichever is the shorter period. When derogatory information is developed in the course of any investigation, the investigation shall be extended to any part of the individual's life necessary to substantiate or disprove the information and to develop adequate information upon which to base a security determination. The investigation may also be expanded when additional investigation is specifically required by competent authority.

SECURITY MANAGEMENT

PROCEDURES

To insure that the requirements of security regulations are met, each command must develop written security procedures. These procedures must specify what is to be done, who is to do it, and who is to supervise it. They must be rewritten as required when changes in Navy security regulations occur, or when changes in the command's assigned functions occur.

These procedures shall also consider requirements for any special or extraordinary control measures that need to be observed to provide the required degree of circulation control. This is especially true whenever automatic data processing equipment is used to process any classified information, or when any printing, duplicating, or reproducing of classified material is accomplished at the local command.

SECURITY MANAGER

The commanding officer is assisted in fulfilling his responsibility for the security of classified material by the security manager. The security manager serves as the commanding officer's direct representative in all cases pertaining to security. He insures that the proper security clearances are obtained, and coordinates a security orientation, education and training program for the protection of classified information.

DISCLOSURES

Classified material may be disseminated to all agencies of the Executive Branch of the Government. On requests from Department of Defense activities, the "need to know" may be judged on the face of the request. When the "need to know" is not discernible from the scope of the requester's activities, classified material shall be sent via the departmental headquarters of the requesting activity for a determination of the requester's "need to know" and capability to handle classified material.

Authority for disclosure of classified military information to foreign governments has been centralized in the Chief of Naval Operations. Accordingly, no command, office, agency, or individual in the Department of the Navy will disclose, direct the disclosure, or permit the disclosure by oral, visual, written communications, or by any other means, to foreign governments or international organizations unless such disclosure has been specifically authorized in writing by the Director of Naval Intelligence, the Vice Chief of Naval Operations, the Chief of Naval Operations, the Assistant Secretary of the Navy (Research and Development), or the Secretary of the Navy.

VIOLATIONS AND COMPROMISES

SECURITY VIOLATIONS

Any person having knowledge of the loss or possible compromise of classified matter must report the fact immediately to his commanding officer. Any violation of regulations pertaining to the safeguarding of classified material but not resulting in compromise or subjection to compromise shall be acted upon by the commanding officer of the individuals involved without reference to higher authority. The fact that a security violation has occurred may, at the discretion of the commanding officer, be considered sufficient justification for some form of formal disciplinary action.

If a container in which classified material is stored is found unlocked in the absence of assigned personnel, such information shall be reported immediately to the senior duty officer. The container shall be guarded until the duty officer arrives at the location of the unlocked container. The duty officer shall then inspect the classified material involved, lock the container, and make a security violation report to the commanding officer. If the duty officer believes that classified information may have been compromised, he shall require the person responsible for the container to return to his ship or station to make a definite inspection report. Appropriate further action shall be taken by the commanding officer or higher authority.

Commanding officers who receive classified material which shows improper handling by the sending activity shall promptly notify that activity's commanding officer. For example, security violations involving improper mailing, shipment, wrapping, packaging or transmission of classified material, or failure to mark or address inner wrappings or envelopes properly should be promptly reported.

Whenever classified information appears to have been compromised as a result of disclosure in a newspaper, magazine, book, pamphlet, radio or television broadcast, or other means of public dissemination, a prompt report shall be made to the Chief of Naval Operations (DNI). Such a report shall fully identify what information is considered classified, the news media concerned (title, date, issue, volume, page, column, station, program, etc.), and the reporter or author involved, and shall cite those portions alleged to reveal classified information. If known, the level of classification and original classifying authority should also be established.

When classified material that has been reported lost is later found and it is determined that, without a doubt, the material has been compromised, this fact shall be reported to all personnel who were notified of the loss.

INQUIRIES

Preliminary Inquiry

When a command receives a report of a compromise and does not have the custodial responsibilities for the material compromised, then that command will conduct a preliminary inquiry and send a report to the command having custodial responsibility. When the command having custodial responsibility cannot be determined, then the command receiving the compromise report will conduct the initial inquiry, which is explained later in this chapter.

The preliminary inquiry consists of informal action to identify accurately the information or material involved, to determine the circumstances of its discovery, to identify all witnesses to the event, and to establish tentatively the degree of probability of compromise. The preliminary inquiry shall be accomplished as quickly as possible and may be reported without any supporting documentation attached.

Initial Inquiry

Upon receipt of a report by an individual of a compromise or suspected compromise, or upon receipt of a preliminary report, the command having custodial responsibility of the material will conduct an initial inquiry. This report will be forwarded to the originator of the subject material with information copies to the chain of command.

Some of the materials included in the report are: complete identification of the compromised material; a brief description of events involved in the compromise; a statement of the commanding officer; and a statement regarding intentions for further investigations.

INVESTIGATIONS

In the Department of the Navy, all investigations are in the form of a Judge Advocate General (JAG) Manual investigation.

The JAG Manual investigation includes:

1. A complete identification of each item of classified material involved.
2. A complete identification of all the individuals mentioned in the report.
3. Findings of fact in the form of a chronology of the circumstances relating to the event.
4. A finding of fact or opinion, as appropriate, establishing a time frame during which the material was subjected to compromise.
5. A finding of fact or opinion, as appropriate, as to the person or persons responsible, if individual culpability is indicated.
6. A finding of fact or opinion, as appropriate, as to the probability of compromise: compromise confirmed; probability of compromise substantial; or probability of compromise remote. If during the course of investigation the determination is made that compromise did not occur, the investigation may be terminated and the recipients of the report of initial inquiry advised, with a brief statement supporting the determination.
7. By reference, enclosure, or finding of fact, affirmation of notification of the originators of the material involved.
8. Recommendation as to remedial action to be taken to prevent recurrence.
9. Recommendation (when required by the appointing order) as to disciplinary action.

This report of investigation is forwarded to the CNO via the chain of command, setting forth approval or disapproval of the proceedings, measures taken to prevent a recurrence, and any disciplinary action taken or recommended.

TRANSMISSION OF CLASSIFIED MATERIAL

Any time material leaves the hands of an originator and is sent on its way to the addressees, it is TRANSMITTED. Whether it goes by courier, by radio, or by mail, if it is classified it has to be safeguarded.

Top Secret material may be transmitted by direct personal contact of officials concerned, Armed Forces Courier Service, or electric means in encrypted form. Top Secret material must not be transmitted through the United States postal system or any foreign postal system.

Secret material may be transmitted in any of the means approved for transmittal of Top

Secret material and by United States registered mail.

Confidential material may be transmitted by any means approved for the transmission of Secret material and by U.S. Postal Service certified or first class mail within U.S. boundaries. U.S. Postal Service registered mail shall be used for all Confidential material of NATO, SEATO, and CENTO; all FPO or APO addressees; and any other addressees when the originator is uncertain whether their location is within U.S. boundaries.

DESTRUCTION OF CLASSIFIED MATERIAL

Classified material not required by a command must not be allowed to accumulate but must either be turned in to the appropriate office or destroyed.

METHODS OF DESTRUCTION

Classified material shall be destroyed in the presence of appropriate officials by burning, melting, chemical decomposition, pulping, pulverizing, shredding, or mutilation sufficient to preclude recognition or reconstruction of the classified material.

During emergency situations at sea, classified material may be jettisoned at depths of 1,000 fathoms or more. If such water depth is not available, and if time does not permit other means of emergency destruction, the material should, nonetheless, be jettisoned to prevent its easy capture. When shipboard emergency destruction plans include jettisoning, document sinking bags should be available. If a vessel is to be sunk through intentional scuttling or is sinking due to hostile action, classified material should be locked in security filing cabinets or vaults and allowed to sink with the vessel rather than attempting jettisoning.

As a last resort, and when none of the methods previously mentioned can be employed, the use of other methods, such as dousing the classified material with a flammable liquid and igniting it, can be used as alternatives to certain loss of the material to the enemy.

The importance of beginning destruction sufficiently early to preclude loss of the material is of paramount importance and must be emphasized. The effects of premature destruction are considered relatively inconsequential when measured against the possibility of compromise. Classified material shall, when practicable, be marked in a manner to indicate its priority for emergency destruction.

RECORDS

Records of destruction are required for Top Secret and Secret material, and shall be dated and signed by two officials witnessing actual destruction; however, if the classified material was placed in burn bags the destruction record will be signed by the witnessing officials at the time the material was placed in the burn bags.

Persons witnessing the destruction of classified material shall:

1. Have a security clearance at least as high as the category of material being destroyed, and they shall be thoroughly familiar with the regulations and procedures for safeguarding classified information.
2. Observe the complete destruction of classified documents.
3. Check residue to determine that destruction is complete and reconstruction is impossible.
4. Take precautions to prevent classified material or burning portions of classified material from being carried away by wind or draft.

A record of destruction is not required for Confidential documents.

APPENDIX I

FORMULAS

Ohm's Law for D-C Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 + \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

RL Circuit Time Constant

$$\frac{\text{L (in henrys)}}{\text{R (in ohms)}} = \text{t (in seconds), or}$$

$$\frac{\text{L (in microhenrys)}}{\text{R (in ohms)}} = \text{t (in microseconds)}$$

RC Circuit Time Constant

R (ohms) x C (farads) = t (seconds)

R (megohms) x C (microfarads) = t (seconds)

R (ohms) x C (microfarads) = t (microseconds)

R (megohms) x C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Capacitors in Parallel: $C_T = C_1 + C_2 + \ldots$

Capacitive Reactance: $X_C = \frac{1}{2\pi fC}$

Impedance in an RC Circuit (Series)

$$Z = \sqrt{R^2 + (X_C)^2}$$

Inductors in Series

$L_T = L_1 + L_2 + \ldots$ (No coupling between coils)

Inductors in Parallel

Two inductors

$L_T = \frac{L_1L_2}{L_1 + L_2}$ (No coupling between coils)

More than two

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots$ (No coupling between coils)

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an RL Circuit (Series)

$$Z = \sqrt{R^2 + (X_L)^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or r.m.s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max}$$
$$= 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}\,(E_{eff}) = 1.414E_{eff}$$
$$= 1.57E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \times P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \times P.F.}$$

Power in A-C Circuit

Apparent power: $P = EI$

True power: $P = EI \cos\theta = EI \times P.F.$

Power Factor

$$P.F. = \frac{P}{EI} = \cos\theta$$

$$\cos\theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44 \times BAfN \times 10^{-8}$$

Turns ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \times \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \times \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With wye connected windings

$$E_{line} = \sqrt{3}(E_{coil}) = 1.732E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil}I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732E_{line}I_{line}$$

(To convert to true power multiply by $\cos \theta$)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{{X_L}^2}{R}$$

$$= QX_L = \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} \text{ (} i_p \text{ constant)}$$

$$\mu = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} \text{ (} e_g \text{ constant)}$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \text{ (} e_p \text{ constant)}$$

Decibels

NOTE: Wherever the expression "log" appears without a subscript specifying the base, the logarithmic base is understood to be 10.

Power ratio

$$db = 10 \log \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

$$db = 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula. When reference level is one milliwatt

$$dbm = 10 \log \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$r.p.m. = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

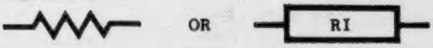
Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force.	Volt, E, or e.m.f.	Gilberts, F, or m.m.f.
Flow	Ampere, I	Flux, Φ, in maxwells
Opposition.	Ohms, R	Reluctance, $\mathcal{R}$
Law.	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm. of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density.	Current density—for example, amperes per cm^2.	Flux density—for example, lines per $cm.^2$, or gausses.

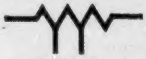
APPENDIX II

SYMBOLS

RESISTORS:



GENERAL



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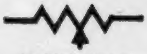
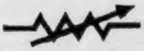
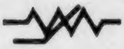


ADJUSTABLE TAP

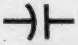


CONTINUOUSLY VARIABLE

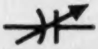


NONLINEAR

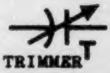
CAPACITORS:



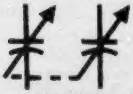
FIXED



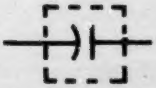
VARIABLE



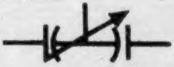
TRIMMER



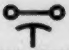
GANGED



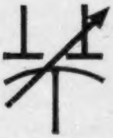
SHIELDED



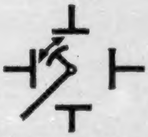
SPLIT-STATOR



FEED-THROUGH



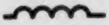
DIFFERENTIAL



PHASE SHIFT

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

INDUCTIVE COMPONENTS:



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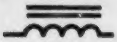
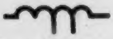


MAGNETIC CORE



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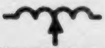
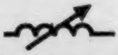
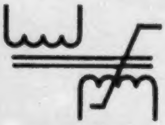


ADJUSTABLE

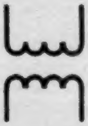


ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE

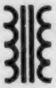


SATURABLE CORE REACTOR

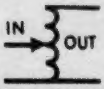
TRANSFORMERS



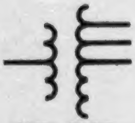
GENERAL



MAGNETIC CORE TRANSFORMER

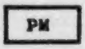


AUTOTRANSFORMER

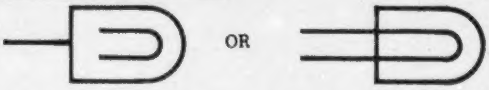


WITH TAPS, SINGLE-PHASE

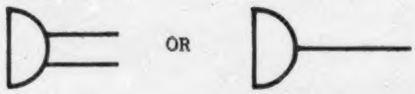
PERMANENT MAGNET



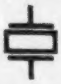
INDICATOR LAMP



MICROPHONE

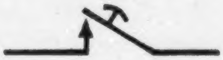


CRYSTAL

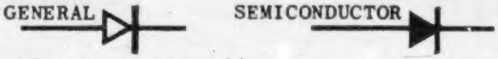


QUARTZ CRYSTAL; PIEZOELECTRIC CRYSTAL UNIT.

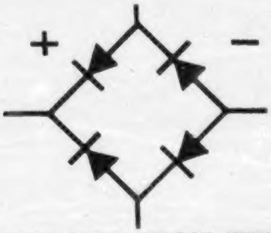
KEY



RECTIFIER

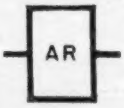


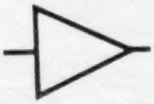
NORMAL CURRENT FLOW IS AGAINST THE ARROW



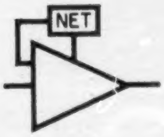
FULL WAVE BRIDGE TYPE

AMPLIFIER





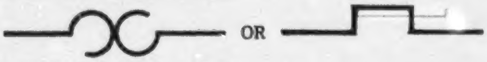
TRIANGLE POINTS IN DIRECTION OF TRANSMISSION (SIGNAL FLOW)



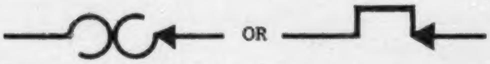
AMPLIFIER WITH EXTERNAL FEEDBACK PATH

BASIC SYMBOL INDICATES ANY METHOD OF AMPLIFICATION EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.

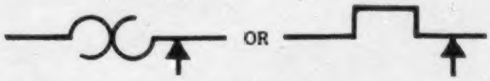
THERMAL ELEMENTS

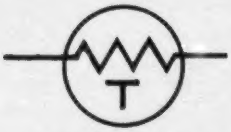


THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

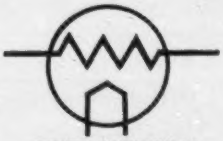


FLASHER; THERMAL CUTOUT

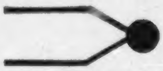




THERMISTOR

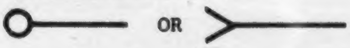


WITH INTEGRAL HEATING ELEMENT

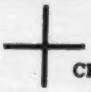


TEMPERATURE-MEASURING THERMOCOUPLE (DISSIMILAR METAL DEVICE)

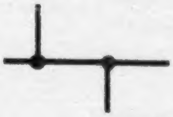
INPUTS (NONSTANDARD)



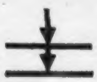
PATH, TRANSMISSION



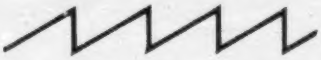
CROSSING NOT CONNECTED



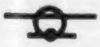
JUNCTION CONNECTED



TWISTED PAIR

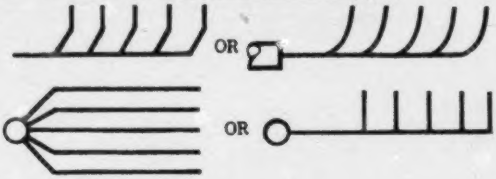


AIR OR SPACE PATH



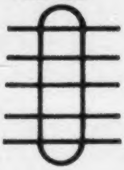
COAXIAL

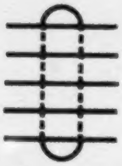
GROUPING OF WIRES IN BUNDLES

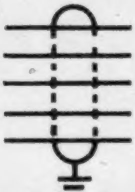


GROUPING OF WIRES IN CABLES

CABLES

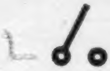

FIVE-CONDUCTOR CABLE

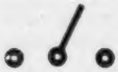

SHIELDED FIVE-CONDUCTOR CABLE

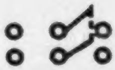

GROUNDED SHIELD

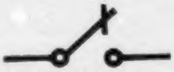
NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

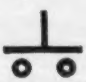
SWITCHES

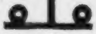

GENERAL (SINGLE THROW)

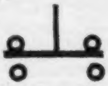

GENERAL (DOUBLE THROW)


TWO POLE DOUBLE THROW SWITCH

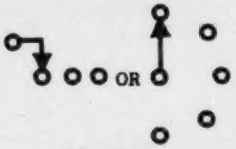

KNIFE SWITCH


PUSHBUTTON (MAKE)


PUSHBUTTON (BREAK)


PUSHBUTTON TWO CIRCUIT

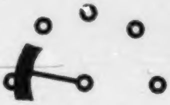
SELECTOR SWITCHES

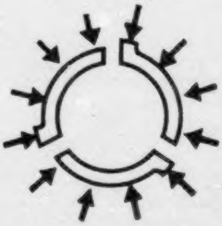


GENERAL

ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK BEFORE MAKE SWITCH.

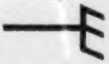
MAKE BEFORE BREAK

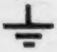



WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

CIRCUIT RETURNS

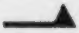
CHASSIS CONNECTION

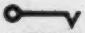

(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

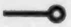
GROUND


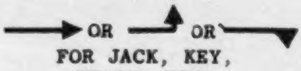
CONTACTS (ELECTRICAL)

SWITCH


MOMENTARY SWITCH


LOCKING

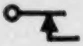

NONLOCKING



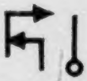
FOR JACK, KEY, RELAY, ETC.

CONTACTS (ELECTRICAL) (Continued)

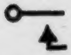
CONTACT ASSEMBLIES



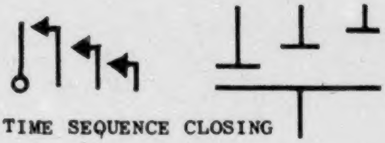
CLOSED CONTACT
(BREAK)



MAKE BEFORE
BREAK

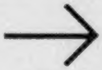


OPEN CONTACT
(MAKE)

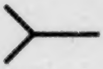


TIME SEQUENCE CLOSING

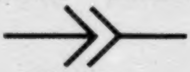
DISCONNECTING DEVICES



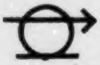
MALE
(PIN CONTACT)



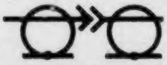
FEMALE
(SOCKET CONTACT)



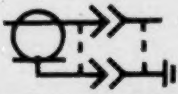
ENGAGED
(PIN-TO-SOCKET)



COAXIAL
(MALE)

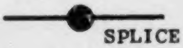


COAXIAL CONNECTORS
MATED

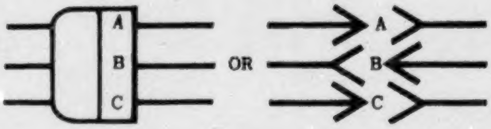


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.



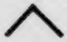
SPLICE



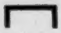
CONNECTOR ASSEMBLY (GENERAL)

ELECTRON TUBES

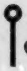
COMPONENT TUBE SYMBOLS



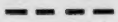
DIRECTLY-HEATED
(FILAMENTARY)
CATHODE



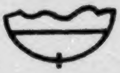
INDIRECTLY-HEATED
CATHODE



COLD
CATHODE

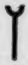


GRID

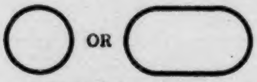


POOL CATHODE

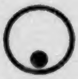
ANODE OR
PLATE



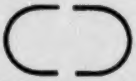
PHOTOCATHODE



ENVELOPE (SHELL)

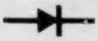


GAS FILLED
ENVELOPE

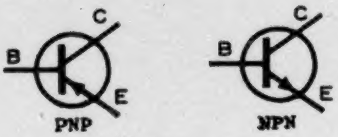


SPLIT ENVELOPE

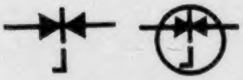
SEMICONDUCTOR DEVICES



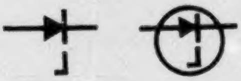
DIODE



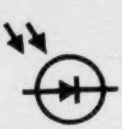
TRANSISTORS



BREAKDOWN DIODE,
BIDIRECTIONAL

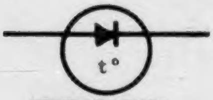


BREAKDOWN DIODE,
UNDIRECTIONAL
(ALSO BACKWARD DIODE)

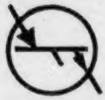


PHOTODIODE

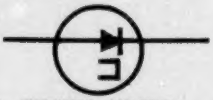
SEMICONDUCTOR DEVICES: (Continued)



TEMPERATURE DEPENDENT DIODE

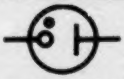


PNPN SWITCH

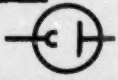


TUNNEL DIODE

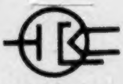
TYPICAL ELECTRON TUBES



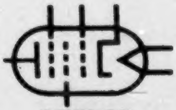
COLD CATHODE GAS TUBE



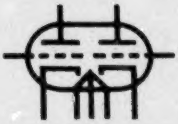
PHOTOTUBE SINGLE UNIT, VACUUM



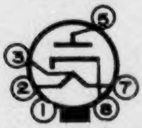
DIODE



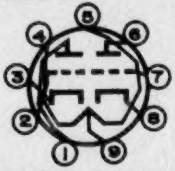
PENTODE



TWIN TRIODE ILLUSTRATING ELONGATED ENVELOPE

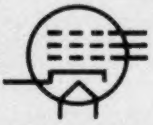


DIODE SHOWING BASE CONNECTIONS

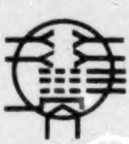


TWIN TRIODE WITH TAPPED HEATER

TYPICAL CATHODE RAY TUBES

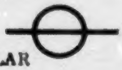


MAGNETIC DEFLECTION

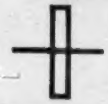


ELECTROSTATIC DEFLECTION

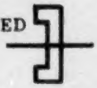
WAVEGUIDES



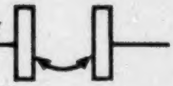
CIRCULAR



RECTANGULAR

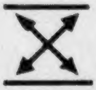


RIDGED

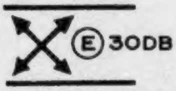


ROTARY JOINT

DIRECTIONAL COUPLERS



GENERAL

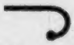


E PLANE APERTURE COUPLING, 30 DB TRANSMISSION LOSS

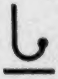
COUPLING METHODS

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

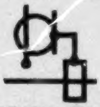
COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

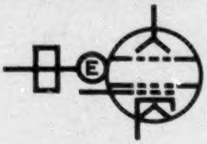


COUPLING BY LOOP TO GUIDED TRANSMISSION PATH

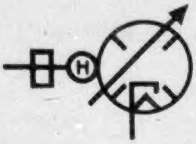


COUPLING BY PROBE FROM COAXIAL TO RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

TYPICAL MAGNETRONS AND KLYSTRONS

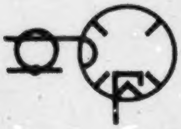


REFLEX KLYSTRON, APERATURE COUPLED

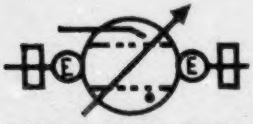


TUNABLE MAGNETRON, APERTURE COUPLED

TYPICAL MAGNETRONS AND KLYSTRONS (Continued)

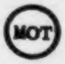


RESONANT TYPE WITH COAXIAL OUTPUT

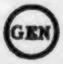


TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

ROTATING MACHINES

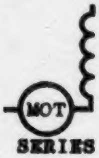


MOTOR

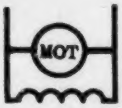


GENERATOR

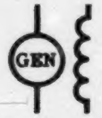
TYPES OF WINDINGS



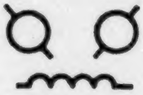
SERIES



SHUNT

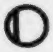


SEPARATELY EXCITED

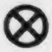


DYNAMOTOR

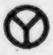
WINDING SYMBOLS



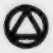
SINGLE-PHASE



TWO - PHASE



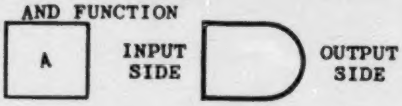
THREE-PHASE (WYE)



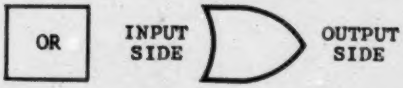
THREE-PHASE (DELTA)

LOGIC FUNCTIONS

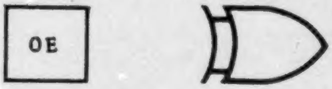
AND FUNCTION


A
INPUT SIDE
OUTPUT SIDE

INCLUSIVE OR FUNCTION

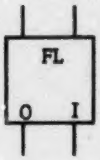

OR
INPUT SIDE
OUTPUT SIDE

EXCLUSIVE OR FUNCTION

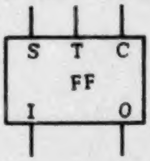


FLIP-FLOPS

LATCH



COMPLEMENTARY

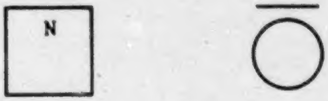


S-SET T-TRIGGER C-CLEAR

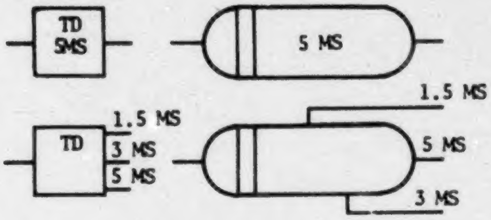
NEGATION

O

ELECTRIC INVERTER

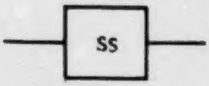


TIME DELAY

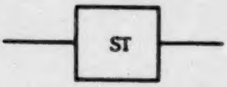

TD
5MS
5 MS
1.5 MS
TD
1.5 MS
3 MS
5 MS
5 MS
3 MS

LOGIC FUNCTIONS (Continued)

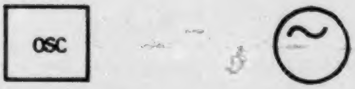
SINGLE SHOT



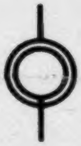
SCHMITT TRIGGER



OSCILLATOR



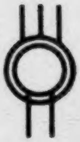
SYNCHROS



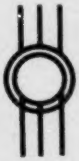
A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

TX - TORQUE TRANSMITTER
TDX - TORQUE DIFFERENTIAL TRANSMITTER
CX - CONTROL TRANSMITTER
CDX - CONTROL DIFFERENTIAL TRANSMITTER
TR - TORQUE RECEIVER
CT - CONTROL TRANSFORMER

SYNCHROS (Continued)

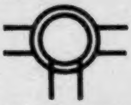


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

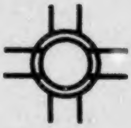


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

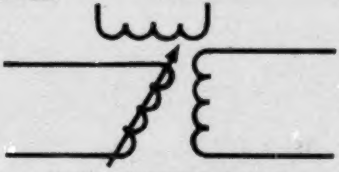


SINGLY-WOUND ROTOR

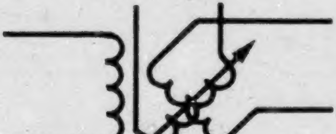


DOUBLY-WOUND ROTOR

RESOLVER

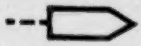


SINGLY-WOUND ROTOR

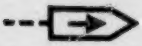


DOUBLY-WOUND ROTOR

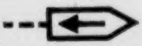
PICKUP HEADS



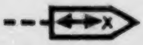
GENERAL



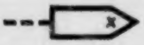
WRITING; RECORDING; HEAD, SOUND RECORDER



READING; PLAYBACK; HEAD, SOUND REPRODUCER

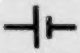


APPLICATION: WRITING, READING, AND ERASING

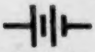


ERASING; ERASER, MAGNETIC

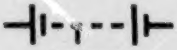
BATTERIES



ONE CELL



MULTICELL

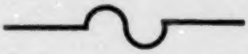


TAPPED MULTICELL

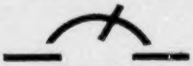
(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

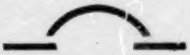
FUSE



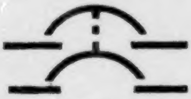
CIRCUIT BREAKERS



SWITCH

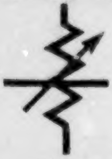


PUSH PULL OR PUSH

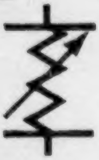


GANGED

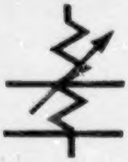
ATTENUATORS



GENERAL



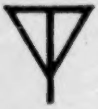
BALANCED



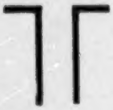
UNBALANCED

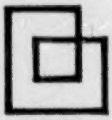
ANTENNAS

GENERAL

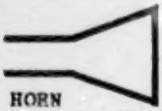


DIPOLE



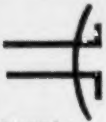


LOOP



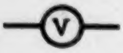
HORN

PARABOLIC



(NONSTANDARD)

METERS



A - AMMETER

CRO - OSCILLOSCOPE

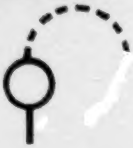
G - GALVANOMETER

MA - MILLIAMMETER

OHM - OHMMETER

V - VOLTMETER

HEADSET



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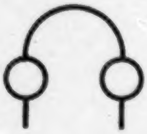

APPENDIX III

LAWS OF EXPONENTS

The International Symbols Committee has adopted prefixes for denoting decimal multiples of units. The National Bureau of Standards has followed the recommendations of this committee, and has adopted the following list of prefixes:

Numbers	Powers of ten	Prefixes	Symbols
1, 000, 000, 000, 000	10^{12}	tera	T
1, 000, 000, 000	10^9	giga	G
1, 000, 000	10^6	mega	M
1, 000	10^3	kilo	k
100	10^2	hecto	h
10	10	deka	da
. 1	10^{-1}	deci	d
. 01	10^{-2}	centi	c
. 001	10^{-3}	milli	m
. 000001	10^{-6}	micro	u
. 000000001	10^{-9}	nano	n
. 000000000001	10^{-12}	pico	p
. 000000000000001	10^{-15}	femto	f
. 000000000000000001	10^{-18}	atto	a

To multiply like (with same base) exponential quantities, add the exponents. In the language of alegebra the rule is $a^m \times a^n = a^{m+n}$

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^{-3} \times 8.252 \times 10^2$$

$$= 24.756 \times 10^{-1} = 2.4756$$

To divide exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \text{ or}$$

$$10^8 \div 10^2 = 10^6$$

$$3,000 \div 0.015 = (3 \times 10^3) \div (1.5 \times 10^{-2})$$

$$= 2 \times 10^5 = 200,000$$

To raise an exponential quantity to a power, multiply the exponents. In the languague of algebra $(x^m)^n = x^{mn}$.

$$(10^3)^4 = 10^{3 \times 4} = 10^{12}$$

$$2,500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6,250,000$$

Any number (except zero) raised to the zero power is one. In the language of algebra $x^0 = 1$

$$x^3 \div x^3 = 1$$

$$10^4 \div 10^4 = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra $x^{-a} = \frac{1}{x^a}$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3,000^3 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, the nth root of $a^m = a^{m/n}$.

$$\sqrt{x^6} = x^{6/2} = x^3$$

$$\sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

APPENDIX IV

GREEK ALPHABET

Name	Capital	Lower Case	Designates
Alpha	Α	α	Angles, coefficient of thermal expansion.
Beta.	Β	β	Angles, flux density.
Gamma.	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon.	Ε	ε	Base of natural logarithms (2.71828).
Zeta.	Ζ	ζ	Impedance, coefficients, coordinates.
Eta	Η	η	Hysteresis coefficient, efficiency, magnetizing force.
Theta	Θ	θ	Phase angle.
Iota	Ι	ι	
Kappa	Κ	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda	Λ	λ	Wavelength.
Mu.	Μ	μ	Permeability, micro, amplification factor.
Nu	Ν	ν	Reluctivity.
Xi	Ξ	ξ	
Omicron	Ο	ο	
Pi	Π	π	3.1416
Rho . . . . . ϖ.	Ρ	ρ	Resistivity.
Sigma.	Σ	σ	Summation symbol (cap).
Tau	Τ	τ	Time constant, time-phase displacement.
Upsilon.	Υ	υ	
Phi	Φ	φ	Angles, magnetic flux.
Chi	Χ	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity (2 π f).

INDEX

Absolute zero, 52
Absorption, 68
Acceleration, 45, 55
Accountability, 119-123
Accountability, classified material, 400
ACM-2905-F22 air conditioner, 272, 274-276
Acoustics:
  disturbances, 87-88
  pressure, 86
Active ECM, 385-393
ADF, 294, 298, 299, 345-352
Adhesion, 50-51
Advancement examination, 4
  qualifications for advancement, 4
AIMS, 371
Airborne auxiliary power units, 268, 270-271
Airborne computers, 230-256
Airborne radar, 354-372
  types, 360-362
Aircraft Application List, NavAir 00-500B, 12
Aircraft Hardware and Consumable Materials, 105-108
Aircraft manuals, 14-20
  01-series, technical, 14-15
  flight, 15
  general, 15
  Illustrated Parts Breakdown, 16-20
  maintenance instructions, 15-16
  miscellaneous, 15
  Periodic Maintenance Requirements, 20
  structural repair, 15
Aircraft Structural Hardware for Aircraft Repair, NA 01-1A-8, 106
Aircraft wire identification coding, 36
Airloc fastener, 108
Air-to-air TACAN, 333-335
All Hands, career publication, 33
Altimeter testing and calibrating, 319, 322
Altimeters:
  AN/APN-120, 313-316
  AN/APN-141(V), 316-319
  bench test and calibration, 319, 322
Ammeter, 126
Amplifier:
  differential, 238-239
  differentiating, 251
  integrating, 254
  isolation, 236-237
  operational, 238-248
  squaring, 246
  summing, 237
AN/AIC-14 intercommunications set, 303-307
AN/AIC-15 intercommunications set, 307-309
AN/ALM-63 test set, 395, 397
AN/ALM-75 test set, 394-395
Analog computers, 231-256
Analyzers, 175-185
  oscilloscope, 176
  spectrum, 183-185
  synchroscope, 176-178, 183
  Tektronix Type 422, 176
  wave, 185
AN/APM-66, radar test set, 190
AN/APN-70 loran, 341-345
AN/APN-120 altimeter, 313-316
AN/APN-141(V) altimeter, 316-319
AN/APQ-107 altimeter warning set, 322, 324-325
AN/ARA-25 direction finder group, 294, 352
AN/ARC-52 radio set, 294-297
AN/ARC-88 radio set, 287-294

AN/ARC-94 radio set, 282-287
AN/ARD-13 ADF, 348-351
AN/ARN-21 transmitter-receiver, 331-336
AN/ARN-32 marker beacon receiver, 331
AN/ARN-41A ADF, 351-352
AN/ARN-52(V) transmitter-receiver, 333, 336-337
AN/ARR-41 radio receiving set, 279-282
AN/ASQ-19 integrated electronic central, 299-303
ANB-M-C1 microphone, 305
Angle of incidence, 63-64
Angle of reflection, 63-64
AN/SRN-6A surface station, 332
Antennas, communications, 309-312
Antennas, ECM:
  direction finding, 385
  pods, 385
  search, 385
Anticycling relay, 262
Antijamming circuits, 262
AN/UPM-32, radar test set, 185-187
AN/UPM-44C, radar test set, 186-187
AN/URN-3A surface station, 332-333
Approach, safety review magazine, 32
Arbitrary zero, 86
Assembly diagrams, 34
Atmospheric conditions, 358-359
AT rating, 1-9
Automatic direction finder, 345-352
  AN/ARA-25, 352
  AN/ARD-13, 348-351
  AN/ARN-41A, 351-352
Auxiliary power units, 265-268
AVCM, 2
Azimuth, 355

Basic Rate Training Manuals, 1
Beam width, 358
Bibliography for Advancement Study, NavTra 10052, i, 7
Billets, instructor, 2
  Enlisted Transfer Manual, NavPers 15909,2
Block diagrams, 34
Boiling, 74-75
Bonding, 210-212
Book circuits, 202
Boyle's Law, 52-53
Burnishing tool, 94

Cable:
  construction, 37
  routing, 37
  splicing, 208
Calculus, 250-254
Camloc stress panel fasteners, 106-108
Candlepower, 75
Cannon plug pliers, 99
Celsius scale, 68-69
Center of gravity, 54
Centimeter, 41
Centrifugal force, 59-60
Chaff dispensers, 390-393
  dispenser test set, 395, 397
Charts and tables, 39
Clamps, wiring support, 209
Classification categories, security, 398
  CONFIDENTIAL, 398
  SECRET, 398
  TOP SECRET, 398
CNI (integrated electronic central), 298-303, 352-353
Coaxial cables, 117
Coaxial connectors, 111-114
Coding, wire identification, 36
Coefficient of expansion, 70-71
Cohesion, 50-51
Color, wavelength, 81
Communications antennas, 309-312
Communications receivers, 279
Communications transmitters, 279
Complimentary color, 81
Component Control Section, 122
Compound, 49-50
Compound bar, figure, 71
Compression waves, 61
Computer:
  airborne, 230-256
  analog, 231-256
  application, 231
  electromechanical, 230
  electronic, 230
  general purpose, 230-231
  hybrid, 230
  mechanical, 230
  special purpose, 230

Conduction, 66-67
Conduction media, 83
Conductor size, 116
CONFIDENTIAL, 398
Connectors:
    coaxial, 111-114
    construction, 109
    designation, 108-109
    miniature, 109-111
    subminiature, 111
Conservation, law of, 44-45
Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NA 00-35QG-016, 120, 122
Continuity test, 192-193
Convection, 67
Conversion factor for units of length, table, 42
Cooling systems, 272, 274-277
    ACM-2905-F22, 272, 274-276
    NR-3, 275, 276
    NR-10, 276
    RCPP 105, 276, 277
Coordinate conversion, polar to rectangular, 248-249
Cordsets, 306-307
Corrosion:
    chemical, 216
    control, 216-219
    electrochemical, 216-217
    prevention, 217-219
    removal, 219-220
Cosine potentiometers, 249
Crimping tool:
    Type MS 3191-3, 98
    Type MS 25037-1, 97-98
Crystal matching, 221-223
Custodial responsibility, 119-120
Custodian, classified material, 399-400
    accountability, 400
    emergency planning, 399
Custody, classified material, 399-401
Cutaway illustration, 33

DAIR, 371-371
D-c generator, 259
DD Form 1348, 122
Decibel, 86-87
Deckedge power, 268, 270-271
Decoy, jamming, 390
Density, 46, 47
Deposited film circuits, 200-201
Destruction of classified material, 404
    method of destruction, 404
    records, 404
Destruct systems, ECM, 393
Diagonal pliers, 98-99
Diagrams:
    assembly, 34
    block, 34
    cutaway, 33
    dimension, 33-34
    location, 33-34
    pictorial, 33
    wiring, 34-36
Differential amplifier, 238-239
Differential voltmeter, 132-135
Differentiating amplifier, 251
Differentiation, 250-252
Differentiator:
    electronic, 250-252
    electromechanical, 252
Diffraction, 65
Digital voltmeter, model 5015 SPA, 135-136
Dimension diagram, 33-34
Direction finder, 294, 381-385
Direction finder, AN/ARA-25, 294
Directives Application List by Aircraft Configuration, NavAir 00-500C, 12-13
Dividers:
    electronic, 243
    electromechanical, 243-245
Doppler effect, 65-66
Doppler navigational radar, 362
Drift, 238

Earphones, 306
Echo, 87
ECM:
    active, 385-393
    passive, 375-385
ECM destruct systems, 393
Elasticity, 51
Electrical summation, 233-235
Electric powerplants, 266-271
Electromechanical computers, 230
Electromechanical differentiator, 252

Electromechanical multiplication methods, 243
Electromechanical summation, 240
Electron, 49
Electronic differentiator, 250-252
Electronic meters, 130-136
Electronic multiplication, 241-242
Electron tube tester, 147-153
Elements, 48
Energy, 43, 44
    kinetic, 57
    laser levels, 90
    potential, 60-61
English measurement, 41
Environmental problems:
    abrasive conditions, 215-216
    corrosion, 216-219
    humidity, 215
    pressurization, 215
    temperature, 215
Equipment and Subject Applicability List, NavAir 00-500D, 13
Equipment Applicability List, NavAir 00-500A, 12
Equipment manuals, 20-28
    Illustrated Parts Breakdown, 28
    nomenclature system 21-22
    Operation Instruction, 22
    Overhaul Instruction, 28
    Radio and radar, 21
    Service Instruction, 22, 28
Expansion:
    coefficient of, 70-71
    thermal, 70-71
    wave, 61

Fahrenheit scale, 68
Fasteners:
    camloc stress panel, 106-108
    airlock, 108
    turnlock, 106-108
F-4B CNI system, 299-303
F-4B electric system, 264
Federal specifications, 29
Federal standards, 29
Flight Manual, 15
Floating body, 47
FM transceiver, 287-294
Foot-candle, 75-76
Foot-lambert,
Force, 42, 45, 54
Frequency, 62
Frequency measurement, 137-147
Friction, 57
Fuses 119
Fusion, 74

Gas, general law, 53
Gas pressure, 52
General aircraft manuals, 15
General gas law, 53
General Order No. 21, 2
Generators:
    d-c, 259
    emergency, 259
Gravity:
    center of, 54
    specific, 46-47
Ground cooling systems, 272, 274-277
Grounded circuit test, 193
Grouped operations (of computers), 254-256

Handbook of Installation Practice for Aircraft Electric and Electronic Wiring, NA 01-1A-505, 98, 117
HD-513/ARC, electronic equipment air cooler, 287, 289
Headsets, 306
Heat, 66-75
    measurement, 73
    nature of, 66
    specific, 73
    transfer, 66-68
Height-finding radar, 361
HERO ordnance hazard, 363-365
HF transceiver, 282-287
Hybrid circuits, 199-200
Hybrid computer, 230

Identity operations, 232
IEC, 298
IFF, 298, 299, 301, 366-372
Illustrated Parts Breakdown (IPB), 16-20, 28
ILS, 329-331
IM-178/ARC-88, standing wave ratio indicator, 287, 289
Impedance matching (between computer devices), 254-255
Implicit solution, 232
Incident ray, 63-64

In-circuit transistor checkers, 155-157
Indicator patterns, ECM, 382-384
Indicators, 358
Inductive resolver, 247-249
Inertia, 45
Instructions and Notices, 29-30
Instrument landing system (ILS), 329-331
Insulated tools, 94
Insulating sleeving, 208-209
Insulation, 116
Integrated COM-NAV-IFF systems, 298-303
Integrated electronic central systems, 352-353
Integrating amplifier, 254
Integration, 252-254
Intensity, illumination, 75-77
Intensity of sound, 84-86
Intercommunications systems, 303-309
Interference, 88
Interrogation, IFF, 367-368
Inventory requirements, 120
Inverse square law of light, table, 76
Inverters, 261
IPB (Illustrated Parts Breakdown), 16-20
Isolation amplifiers, 236-237

Jamming transmitter, 386-388

Kelvin scale, 69-70
Kilometer, 41
Kinetic energy, 47-48, 57

Lacing and tying wire, 209-210
Lasers, 89-92
Law of conservation, 44-45
Laws of motion, 56
LDO, 2
Leadership, 2
    General Order No. 21, 2
Lense:
    negative, 80
    positive, 80
Light, 75-82
Linear functions, 233-245
Line support equipment, 187-190
    altimeter, 190
    IFF, 187
    radar, 188-189
    tacan, 187-188
Liquids, 51
Liquid thermometers, 72
Location and dimension diagrams, 33-34
Logarithmic computation, 232
Logarithmic shaping network, 249-250
Longitudinal waves, 60-61
Loran, 338-345
    AN/APN-70, 341-345
Lumen, 76-77
Luminance, 77
Lux, 77

Magnetrons, 221
Maintenance by exception, 197-198
Maintenance Instructions Manual, 15-16
Manual of Qualifications for Advancement, NavPers 18068, i, 4-5
    quals, i, 1, 4-5
MARC's, 119
Marker beacon receiver AN/ARN-32, 331
Marker beacons, 330-331
Masers, 89-92
Mass, 42, 54
Material Accountability Recoverability Codes (MARC's), 119
Material requisitioning, 121
Matter, 44, 45, 48-54
Mechanical advantage, 58-59
Mechanical computers, 230
Mechanical equivalent, 73
Mechanics, 54-60
Mech, aviation safety review, 53
Meters, 125-147
    ammeter, 126
    electronic voltmeters, 130-136
        differential, 132-135
        digital, 135-136
        phase angle, 131-132
        vacuum tube, 130-131
    frequency, 137-147
        AN/USM-26, 139-140
        digital, 144-147
        electronic 140-144
    nonelectronic, 127-130
        multimeter, 127-130
    ohmeter, 126
    voltmeter, 127
Metric measurement, 41

Microelectronics, 198-199, 200
    application, 201
Micromaintenance, 202
Microminiaturization, 198-199
Micron, 41
Micropackaging, 200
Microphones, 305.306
Microwave crystal test set, 153-155
Military requirements for advancement, 4
Military specifications, 29
Military standards, 29
Millimeter, 41
Miniature connectors, 109-111
Miniaturization, 199
    applications, 201
Mixture, 49-50
Mobile electric powerplants:
    NC-8A, 266
    NC-10B, 266-268
    NC-12 and NC-12A, 268
Modulation measurement, 175
Modules, 202
Molecule, 49
Momentum, 56
Motion, 54-56
Motion, wave, 82-83
Mounting parts, 105
Multimeter, 127-130
Multiplication:
    electromechanical methods, 243
    electronic methods, 241-242

NAPI, Publications Index, 11
Nautical mile, 41
NavAir 00-500A, Equipment Applicability List, 12
NavAir 00-500B, Aircraft Application List, 12
NavAir 00-500C, Directives Application, 12-13
NavAir 00-500D, Equipment and Subject Applicability, 13
Naval Aeronautic Publications Index (NAPI), 11
Naval Aviation News, 32
Naval Ordnance Bulletin, 32-33
Navigation, 362
Navigational radar, 362
Navigation equipment, 313-353
NavPers 18068, "Quals" Manual, i, 4-5
NavSup 2002, Navy Stock List of Forms and Publications, 11-12
NavTra 10052, Bibliography, i, 7
NavTra 1414/1, Record of Practical Factors, 4, 6-7
Navy Stock List of Forms and Publications, NavSup 2002, 11-12
NC-8A, MEPP, 266
NC-10B, MEPP, 266-268
NC-12 and NC-12A, MEPP, 268
Negative lens, 80
Nonelectronic jamming:
    decoys, 390
    rope, 390
    window, 389-390
Nonelectronic meters, 127-130
Nonlinear functions, 245-250
Nonmagnetic tools, 93-94
Nonresident career course, 4
Notices and Instructions, 29-30
NR-3, MEPP, 275-276
NR-10, MEPP, 276
Nucleus, 48
Numbering system for publications, 13-14

Octopus, 157-160
Ohmeter, 126
Omnidirectional range, 325-329
Operational amplifier, 238-240
Operation Instruction Manual, 22
Ordnance hazards (HERO), 363-365
Oscilloscope, Tektronix Type 422, 176
Overhaul Instruction Manual, 28
Overvoltage relay, 261

P-3C electric system, 262
Panoramic adapters, 379-380
Passive ECM, 375-385
Paths of advancement, 3
    rating structure, 1-3
Peak power, 357-358
Period, 62
Periodic Maintenance Requirements Manual (PMRM), 20
Personnel Qualification Standards (PQS), 5-6
Phase angle voltmeter, 131-132
Phot, 77
Photon, 89
Pictorial illustrations, 33

Pins, taper, 94-96
Pitch of wound, 84
Pliers:
    cannon plug, 99
    diagonal, 98-99
PMRM (Periodic Maintenance Requirements Manual), 20
Point bender, 94
Polar to rectangular coordinate conversion, 248-249
Population inversion, 90
Positive lense, 80
Potential energy, 60-61
Potentiometers, sine and cosine, 249
Potting compound, 117-119
Potting procedure, 118-119
Power, 43-44, 56-59
Power conversion devices:
    inverters, 261
    transformer-rectifiers, 261
Power, deckedge, 268, 270-271
Power ratio, 86-87
Powers (of a term), 246-247
Power units, 265-268
PQS, Personnel Qualification Standards, 5-6
Pressure, 47
Pressure, acoustical, 86
Pressure, gas, 52
Primary colors, 81
Printed circuit repair tools, 100-105
Printed circuits, 202-204
Prisms, 78-79
Protective devices, 261-262, 264
    anticycling relay, 262
    overvoltage relay, 261
    transfer relay, 262
    undervoltage relay, 261-262
Proton, 48
Pulse analyzer, 380-381
Pulse generator:
    AN/UPM-55, 171
    AN/URM-44A, 170-171
    pulse-modulated RF model 628A, 172
Pulse-modulated RF signal generator model 628A, 172-175
Pulse width, 358

Qualification for advancement, 4
Quals, i, 1
    qualifications for advancement, 4

R-648/ARR-41 receiver, 279-282
Radar altimeter warning set (RAWS), AN/APQ-107, 322, 324-325
Radar characteristics, 354-356
Radar principles, 354-360
Radiation, 67-68
Radio ranges, 325-329
Radio receiving set AN/ARR-41, 279-282
Range, 354-355
Rankine scale, 70
Rating structure, advancement, 1-3
    AVCM, 2
    LDO, 2
    Warrant Officer, 2
RAWS, AN/APQ-107, 322, 324-325
Rays, 63
RCPP 105 power and refrigeration unit, 276, 277
Receivers, communications, 279
Receiving set AN/ARR-41, 279-282
Record of Practical Factors, NavTra 1414/1, 4, 6-7
Rectifiers, 264-265
Reflection, 63-64, 77-78
Refraction, 64-65, 78-81
Relay, communications, 294-297
Relay tools, 94
Reordering tools, 120
Requirements for security clearance, 400-401
Resistance checks, 196-197
Resistance thermometers, 72
Resolution, 355, 356
Resolver, inductive, 247-249
Resonance, 88
Reverberation, 87-88
Revision of manuals, 28
    reporting errors, 28-29
RF radiation hazards, 362-366
    fuel, 366
    miscellaneous, 366
    ordnance, 363-365
    personnel, 365-366
RF signal generators, 393-394
Right triangle solver, 255-256
Roots (of a term), 246-247
Rope, jamming, 390
RT-322/ARC-52 receiver-transmitter, 294, 295-297

RT-424/ARC-52X receiver-transmitter, 294, 295-297
RT-649/ARC-88 receiver-transmitter, 287-294

SACE, 227-228
Safety wiring, 212-214
Salvage procedures, 220
Scale factor 232-233, 235-236, 254
Schematics, 37-39
Search radar, 360-361
SECRET, 398
Section G Allowance List, NA 00-35QG-0 Series, 119, 123
Security, 398-404
    classification categories, 398
    custody, 399-401
    destruction of classified material, 404
    security management, 401-402
    transmission of classified material, 403-404
    types of personnel security investigations, 404
Security clearance, 400
Security management:
    disclosures, 402
    manager, 401-402
    procedures, 401
Selective identification feature (SIF), 368-371
Semiconductor growth, 201
Semiconductor testers, 153-166
Semiconductors, 204-207
    base arrangement, 204-205
    designation, 204
    handling, 206-207
    measurements, 205-206
    servicing, 207
Service Instruction Manual, 22, 28
Shaping network, logarithmic, 249-250
Shock mounts, 212
Shop tools, 123
Short test, 193-194
Side-looking radar, 361-362
SIF, 299, 301, 368-371
Signal characteristics, 373-375, 382
    beam width, 374
    carrier frequency, 373
    polarization, 374-375
    PRF, 373-374
    pulse width, 374
    scan type and rate, 374
Signal generators, 166-175
    multiple-signal, 171-172
    pulse AN/UPM-55, 171
    pulse AN/URM-44A, 170
    pulse-modulated, RF, model 628A, 172-175
    sine wave, 167-170
    sweep AN/URM-75, 170
Signal tracing, 194-195
Silk screen circuits, 201
Sine potentiometers, 249
Sine wave generators, 167-170
Single sideband transceiver, 282-287
Sleeving, insulating, 208-209
Slug, 42
Solids, 50-51
Solidstate integrated circuits, 200
Solid thermometers, 72
Sound, 82-88
    intensity, 84-85
    measurement, 85-87
    pitch, 84
    quality, 84
    units, 85-86
Special tools, 93, 123
Specifications, equipment, 29
    federal, 29
    military, 29
Specific gravity, 46-47
Specific heat, 73
Spectrum analyzer, 183-185
Splicing, cable, 208
Squaring amplifier, 246
Squaring type triangle solver, 255-256
Standards, 29
    federal, 29
    military, 29
Standing waves, 62
States of matter, 50-54
Stowage, classified material:
    combinations, 399
    numerical evaluation system, 399
Stripper:
    thermal wire, 102-105
    wire and cable, 96-97
Structural repair manuals, 15
Structure of matter, 48-54
Study suggestions, 7-8

Subminiature connectors, 111
Summation:
  electrical, 233-235
  electromechanical, 240
Summing amplifiers, 237
Supply Activity mission, 121
Supply Response Section, 122
Supply Support Center, 121-122
Support clamps, wiring, 209
Support equipment (test equipment), 124-190
Sweep generator AN/URM-75, 170
Synchroscope, 176-178, 183

Tables and charts, 39
TACAN, 298, 299, 301, 331-338
  air-to-air, 333-335
  AN/ARN-21, 331-335
  AN/ARN-52(V), 333, 336-337
  AN/SRN-6A, 332
  AN/URN-3A, 332-333
  test and alinement, 337-338
Taper pins, 94-96
Technical Directive System, 30-32
Tektronix 422 oscilloscope, 176
Tektronix 575 transistor curve tracer, 162-166
Temperature, 68-73
  inversion, 68-70
Tensile strength, 51
Terminal board repair, 207-208
Terminal junction systems, 114-115
Test equipment (support equipment), 124-190
Testing with support equipment, 223-227
Test probes, 195
Thermal expansion, 70-71
Thermal wire stripper, 102-105
Thermocouple, 72-73
Thermometers, 72-73
Thermostat, figure, 71
Thin-film devices, 200
Toolbox:
  crew leaders, 122
  individual, 122
Tool cribs, 123
Tool kits, 122-123
Tools:
  burnishing, 94
  crimping, 97-98
  insulated, 94
  inventory requirements, 120
  nonmagnetic, 93-94
  printed circuit repair, 100-105
  relay, 94
  reordering, 120
  shop, 123
  special, 93, 123
  wire and cable, 94-96
Tools and Their Uses, NavPers 10085-B, 93, 98
TOP SECRET, 398
Torque, 56
Total force, 47
Transceiver, AN/ARC-52, 294-297
Transceiver, AN/ARC-94, 282-287
Transceiver, FM, 287-294
Transceiver, UHF, 287-294
Transfer of heat, 66-68
Transfer relay, 262
Transformer-rectifiers, 261, 264-465
Transistor cruve tracer (Tektronix 575), 162-166
Transistors (semiconductors), 204-207
Transistor testers, 153-166
Translational, 56
Transmission of classified material, 403-404
Transmission, velocity of, 83
Transmitters, communications, 279
Transmutation, 48
Transverse waves, 60
Triangle solver (right), 255, 256
Trigonometric functions, 247-249
Troubleshooting, 191-197
  basic tests, 192-196
  bench procedures, 194-197
Turnlock fasteners, 106-108
Tying and lacing wire, 209-210
Types of personnel security investigations:
  Background Investigation, 401
  National Agency Check and Inquiry, 401

UHF transceiver, 287-294
Ultrasonic cleaning, 220
Undervoltage relay, 261
Units of measurement, table, 41
Units of sound, 85

Vacuum tube tester, 147-153
Vacuum tube voltmeter (VTVM), 130-131
Vaporization, 74
VAST, 228-229
Vector, 46
Velocity, 43, 61
Velocity of transmission, 83
Violations and compromises, classified material:
    inquiries, 403
    investigations, 403
    security violations, 402
Voltage regulation, 259
Voltmeter:
    differential, 132-135
    digital, 135-136
    multimeter, 127-130
    phase angle, 131-132
    VTVM, 130-131
VOR, 325-329
VTVM, 130-131

Warrant Officer, 2
Wave analyzer, 185
Waveform measurement, 175-176
Wavefront, 63
Wavelength, 62
Wavelength, color, 81
Wave motion, 60, 82-83
Wave parameter, 60-66
Wave traps, 378-379
Weight, 42
Window, jamming, 389-390
Wire, 115-116
    identification, 116
    insulation, 116
    size, 116
Wire and cable stripper, 96-97
Wire and cable tools, 94-96
Wire, coding identification, 36
Wiring diagrams, 34-36
Work, 43, 56-59

Zero, absolute, 52
Zero, arbitrary, 86

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